37

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MAY 1941

THE JOURNAL
OF
THE INSTITUTION OF ELECTRICAL ENGINEERS

ISSUED IN THREE PARTS

PART I. GENERAL (*Monthly*) PART II. POWER ENGINEERING (*Alternate Months*)
PART III. COMMUNICATION ENGINEERING (*Quarterly*)

PART I. GENERAL

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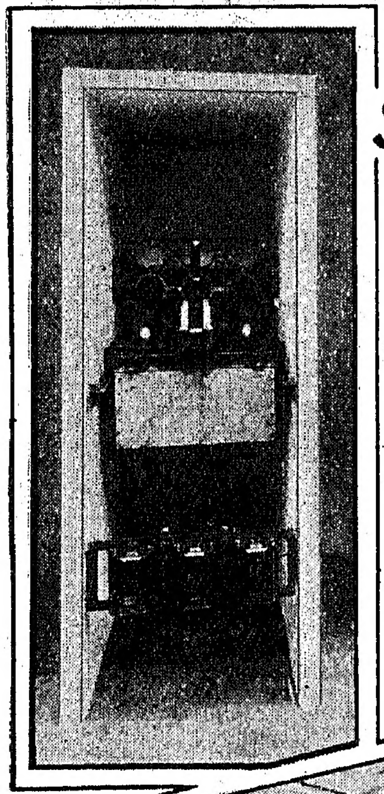

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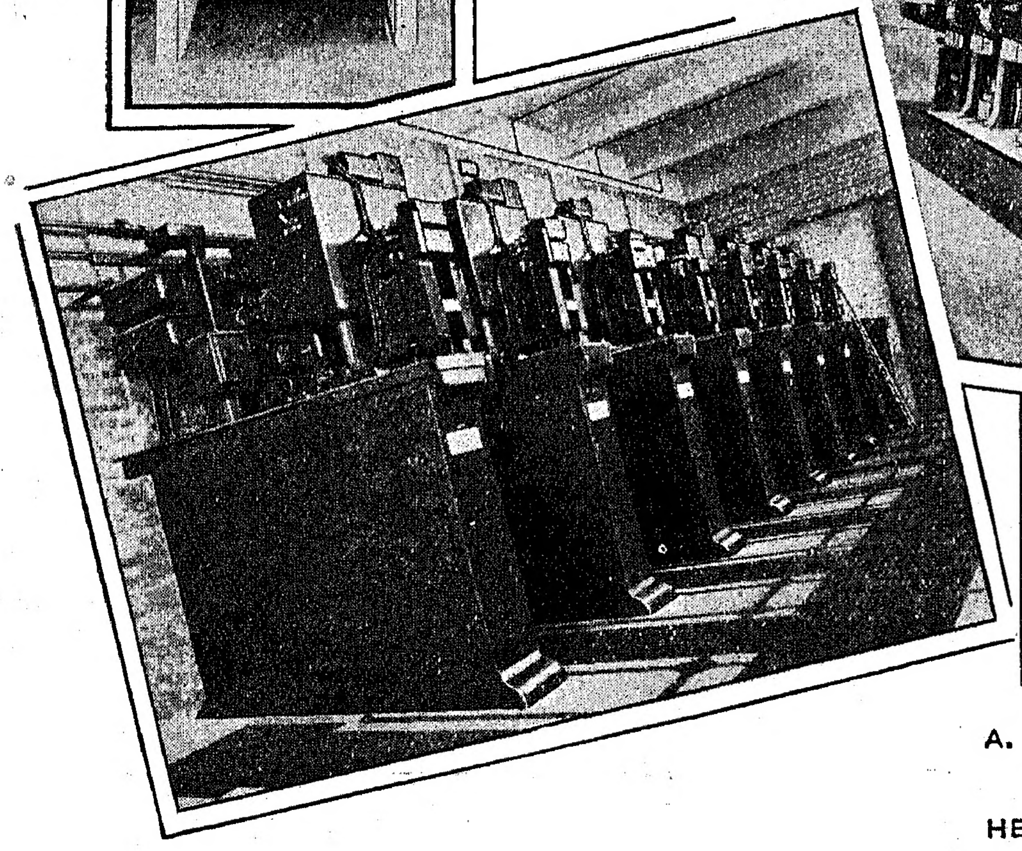

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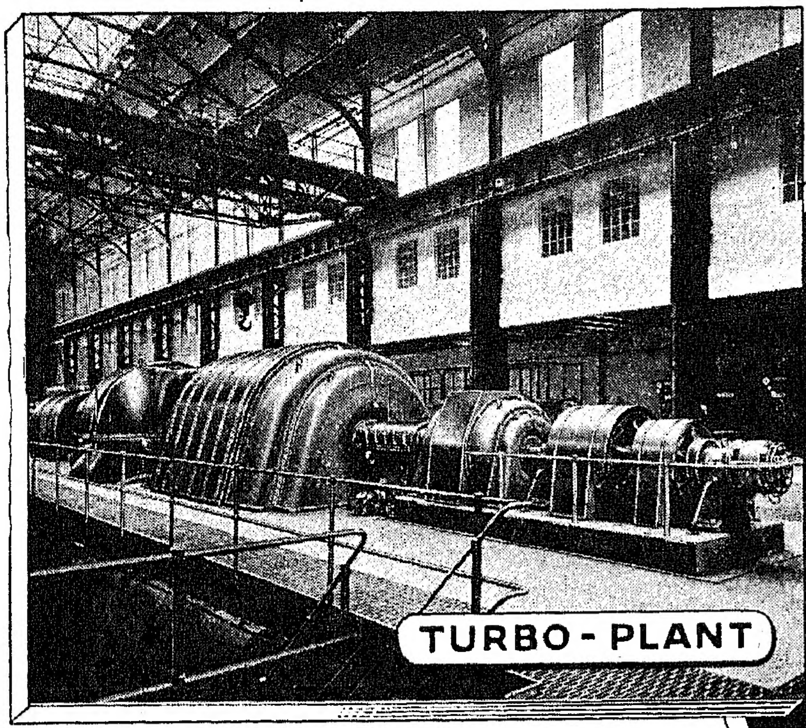

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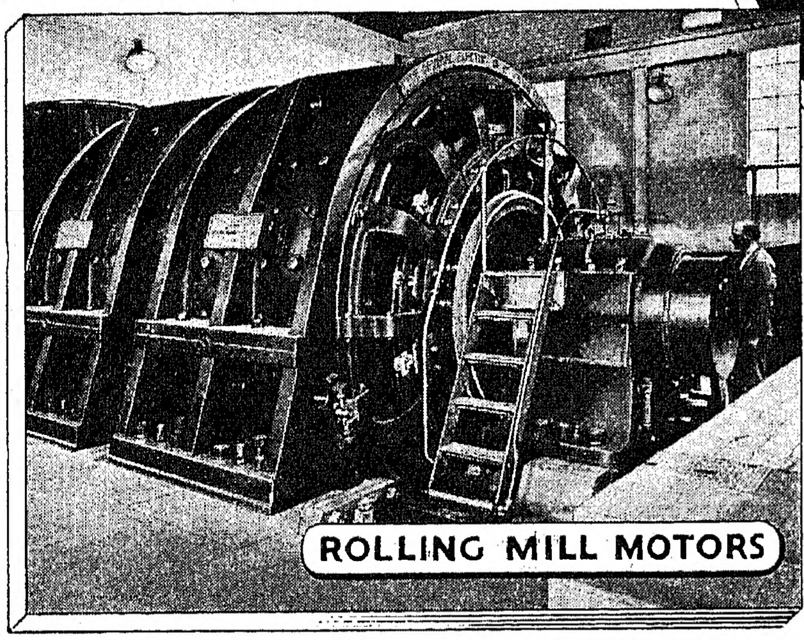

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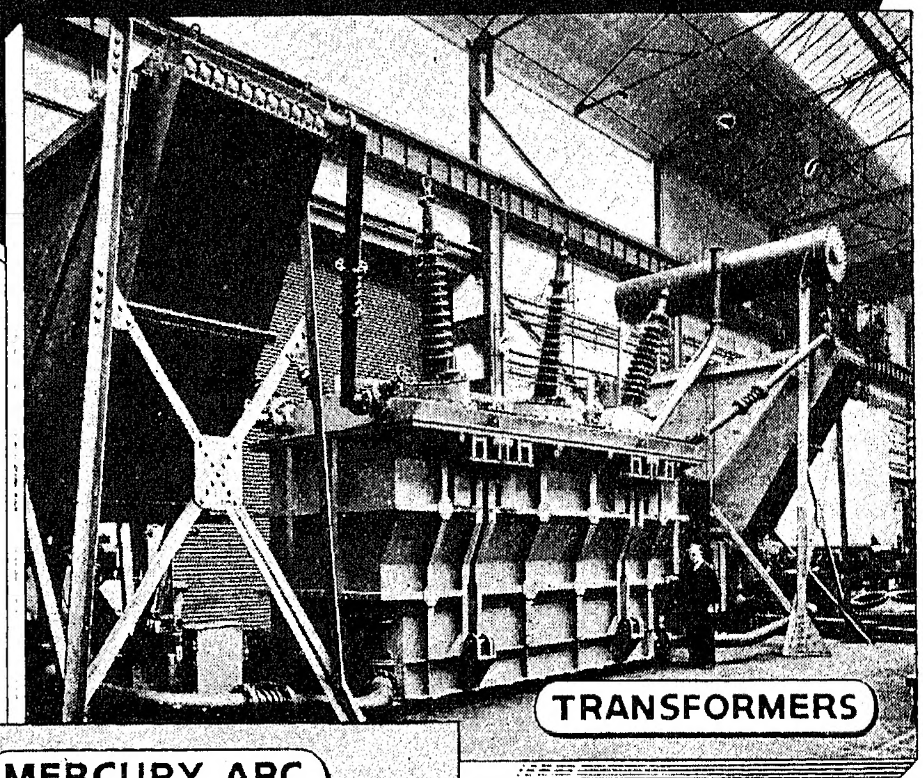

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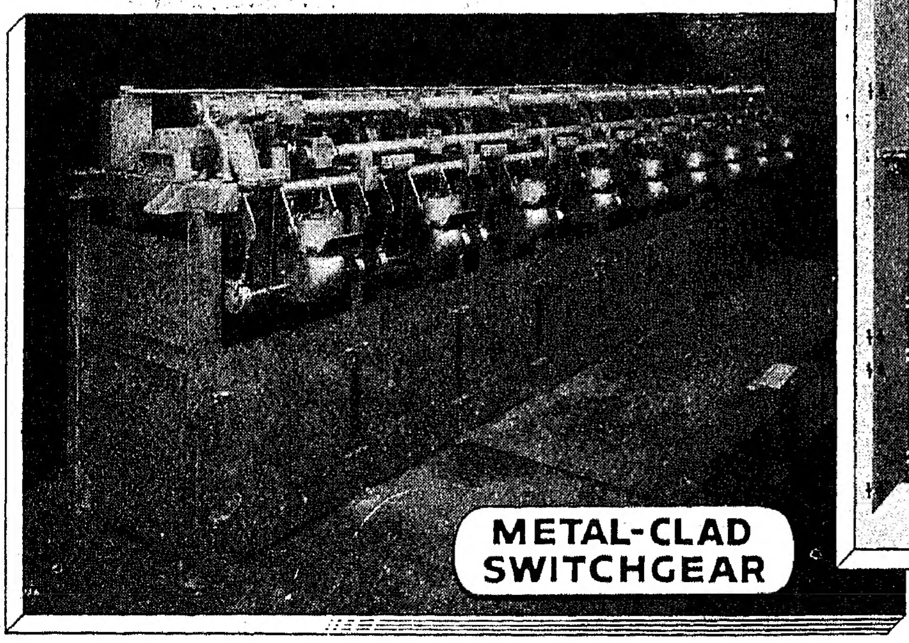

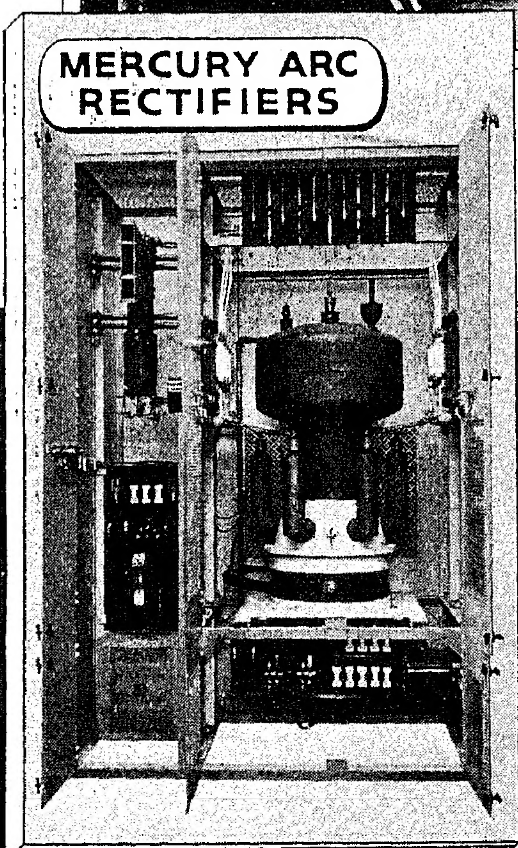

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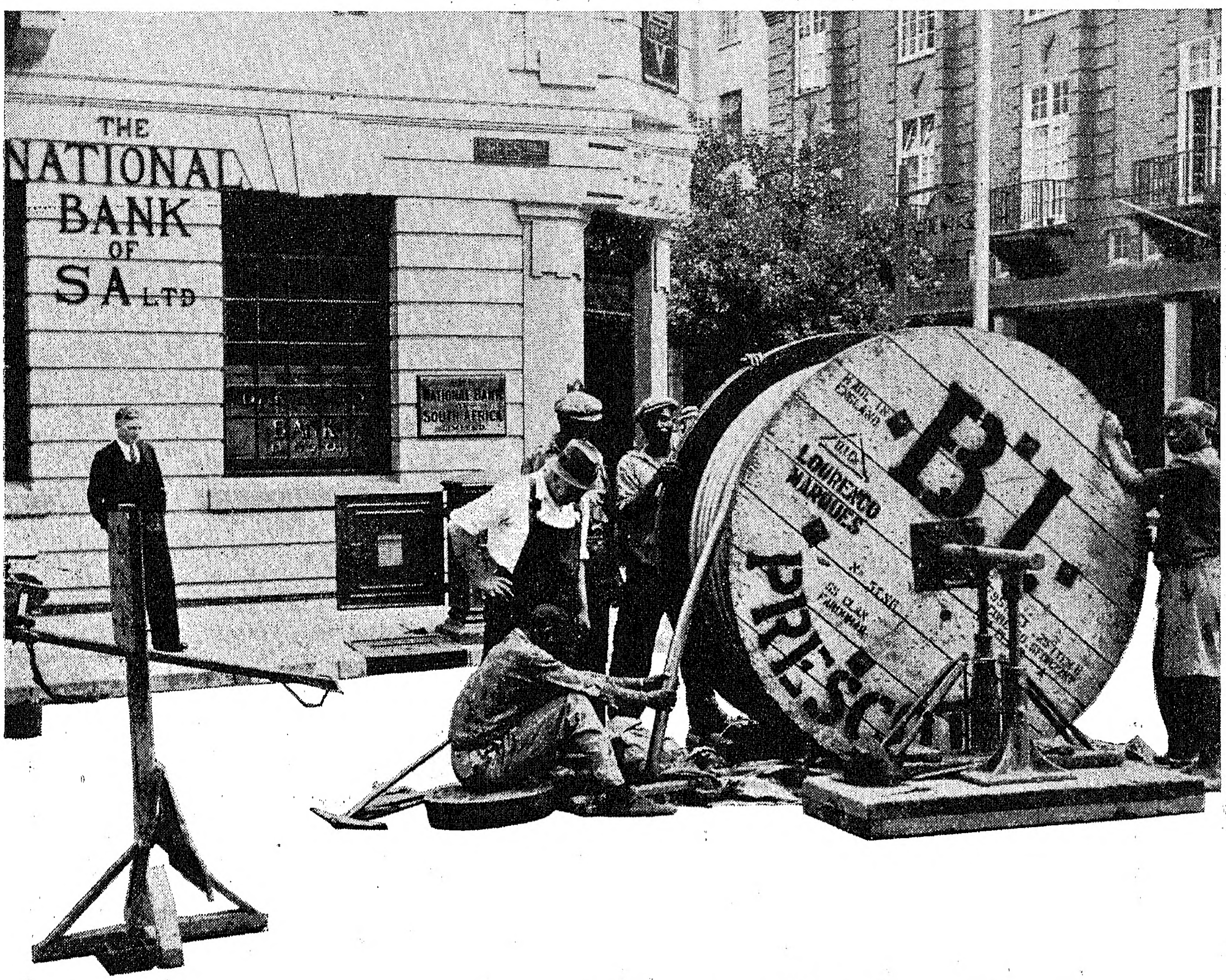

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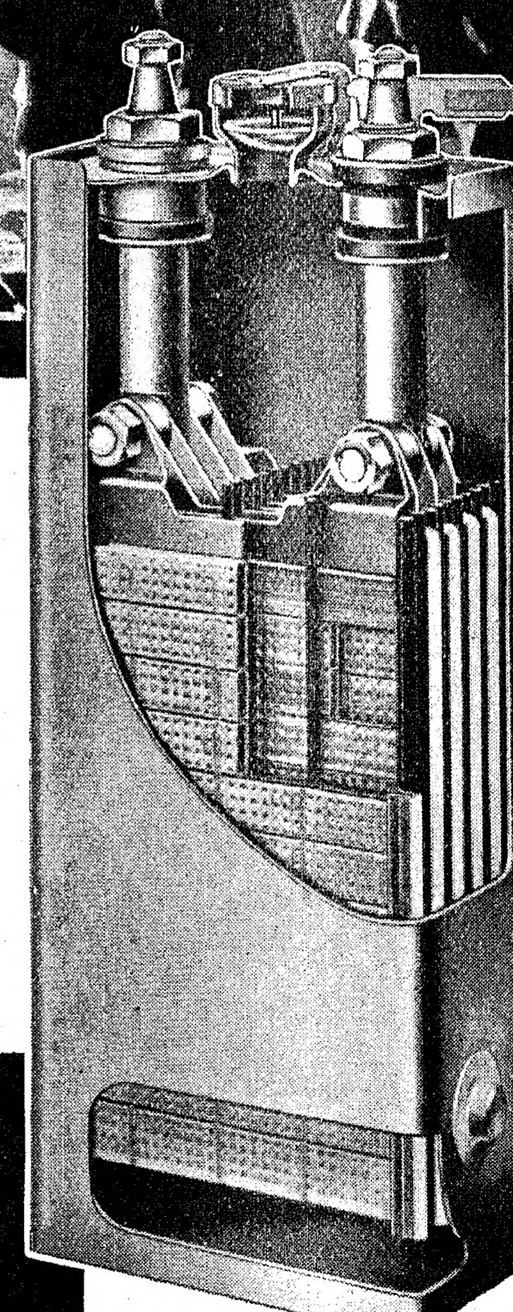

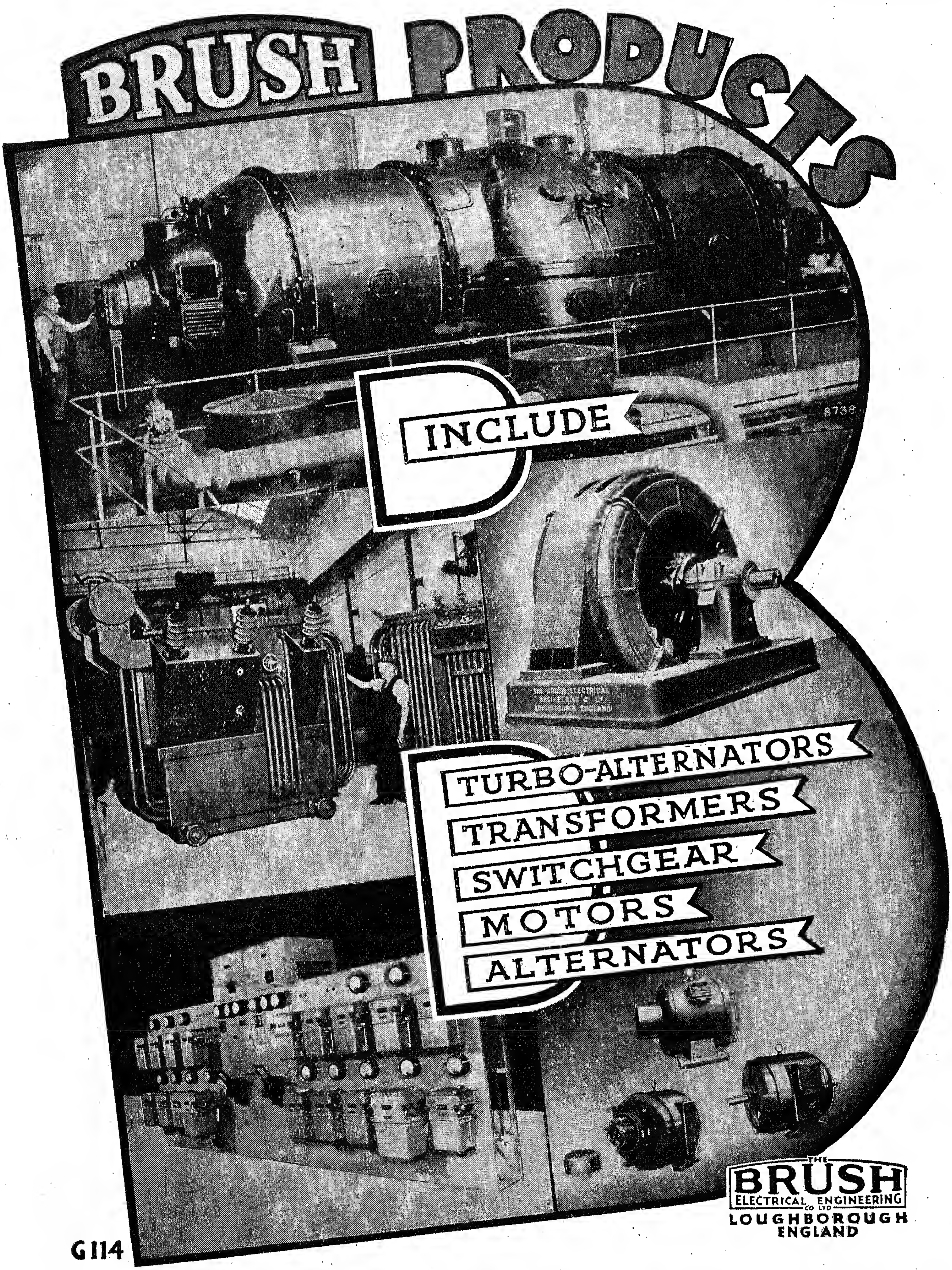

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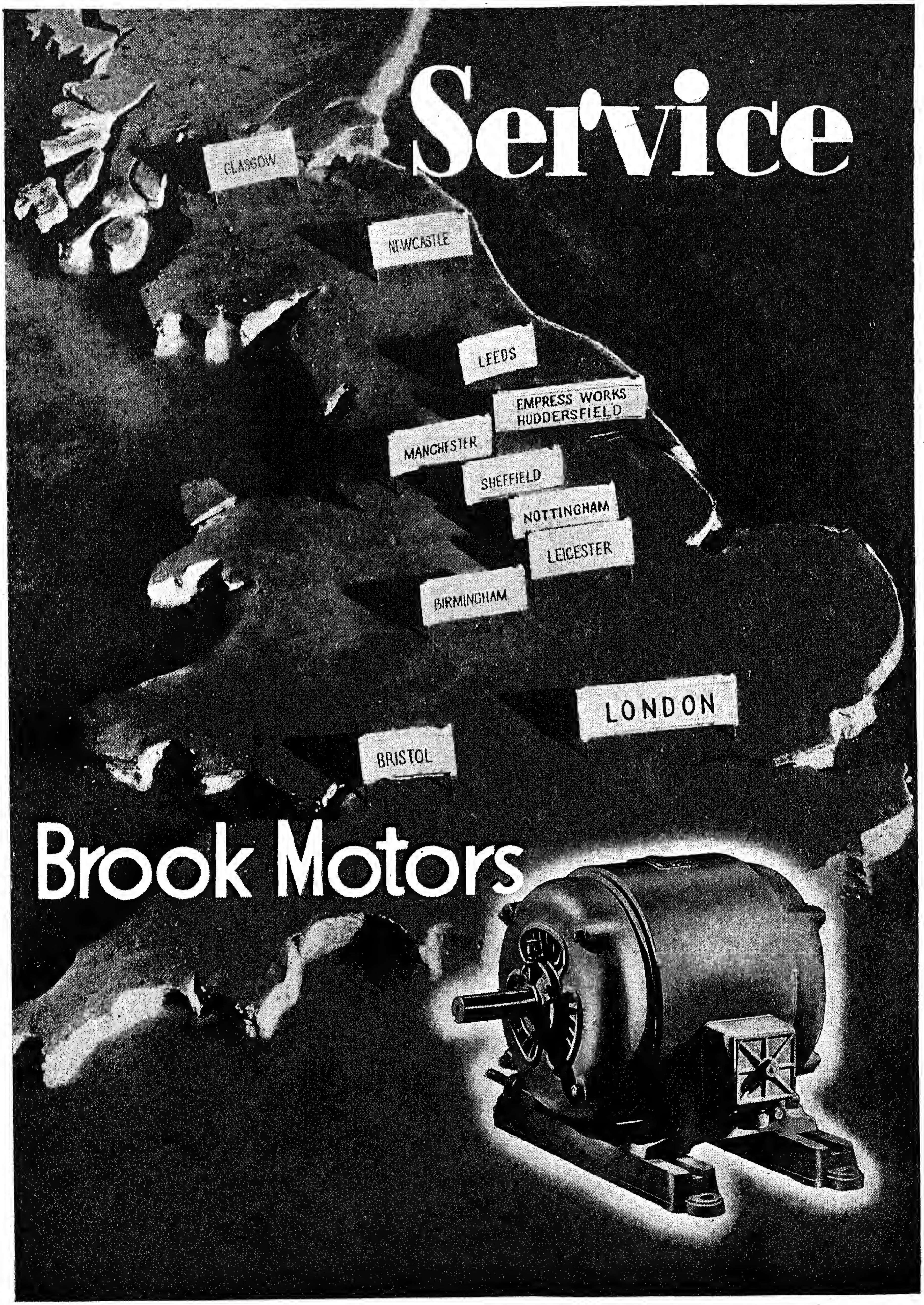
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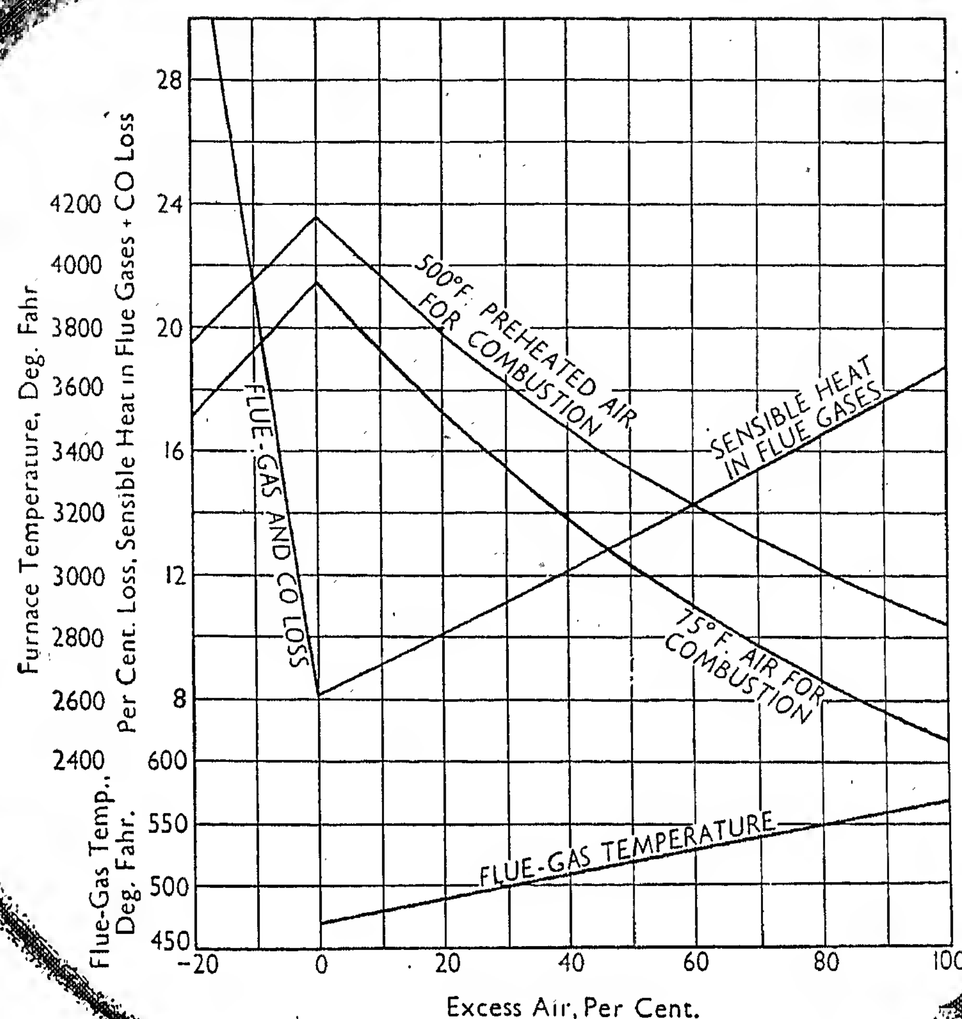

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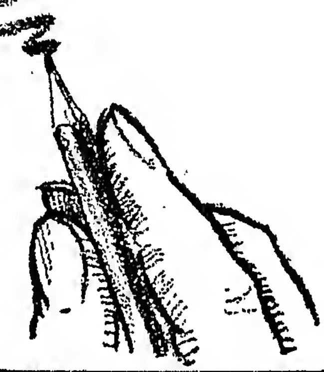

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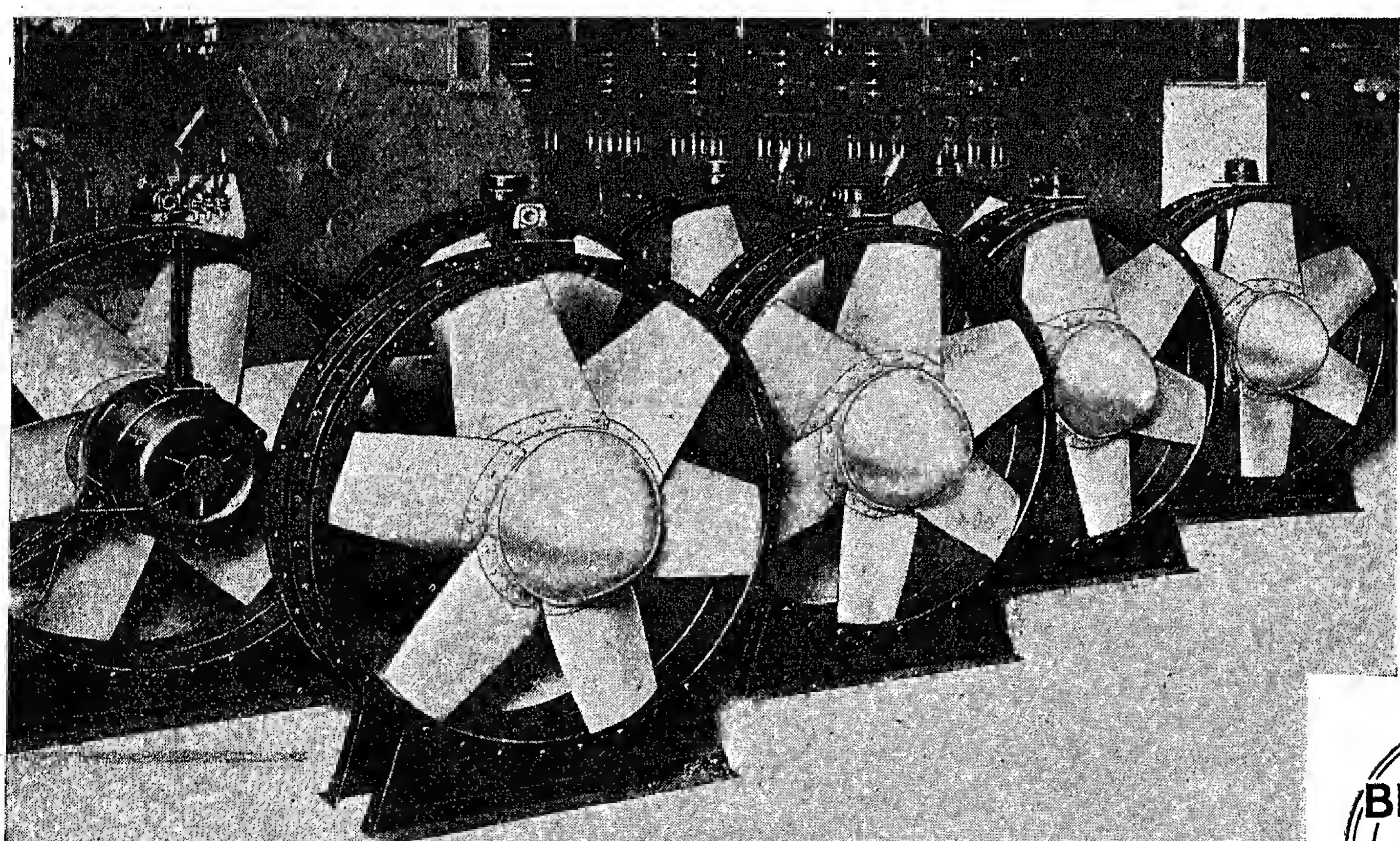

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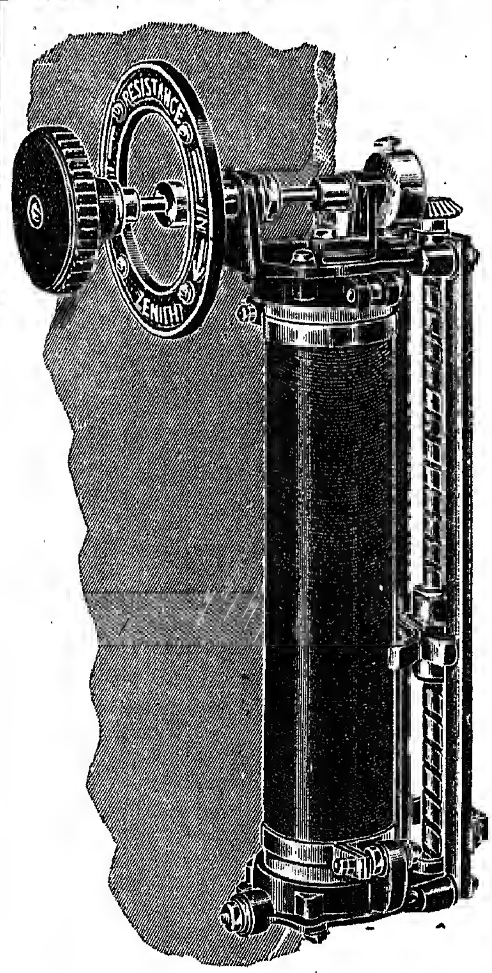

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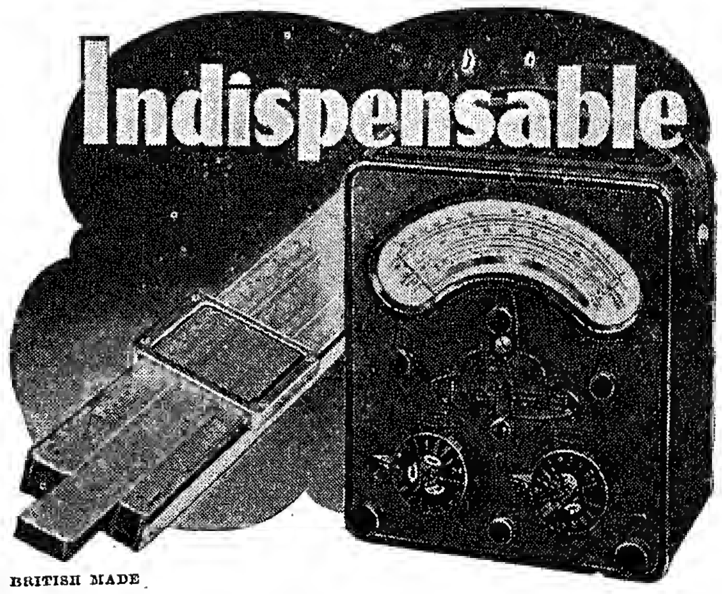

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THE JOURNAL OF THE INSTITUTION OF ELECTRICAL ENGINEERS

EDITED BY W. K. BRASHER, SECRETARY

VOL. 88. PART I (GENERAL), No. 5. MAY 1941

"THE HISTORY OF THE INSTITUTION"

The preparation of the handsome and dignified crown quarto volume in which the history of the first 60 years of The Institution of Electrical Engineers is now recorded was initiated by the Council in January, 1937, when a small special Committee was appointed to develop the project and to see it through.

The History, which was published in the autumn of 1939, was planned to cover the 60-years period from the inception of The Institution in 1871 to the significant electrical landmark represented by the Faraday Centenary in 1931. It is best that a history should not be written up too closely to the events it records, and it was felt that the omission of the noteworthy events in the progress of The Institution during the last few years would be more than made good by the better perspective in which they could be recorded in some succeeding volume.

Future generations of electrical engineers will be glad that the first historical account of The Institution has been undertaken while the activities and achievements of those of its earliest pioneers who are no longer alive still remain fresh in the recollection of their surviving friends.

The primary work of collecting the material, and the writing of the narrative, were placed in the hands of Mr. Rollo Appleyard, with full confidence that his well-known literary ability and genius for historical research would be devoted to a task that would be for him a labour of love. This confidence he has fully justified: he has produced no dry or stodgy compendium, no bald record of events, but on the contrary a most readable and human story, enlivened by many lighthearted incidents and shrewd comments.

The book has as a frontispiece a beautiful three-colour view of the Institution building, and is well illustrated throughout. An introductory chapter takes account of the state of electrical knowledge prior to 1871, and this is followed by a chapter on "The Founders," descriptive of the personalities, and the doings and discussions, of those who launched The Institution in May, 1871, as "The Society of Telegraph Engineers" with 66 members. Stage by stage the advances of the subsequent 60 years are then reviewed with the comedies and tragedies, the triumphs and the disappointments, which have attended that wonderful epoch in the development of electrical science and practice.

Mr. Appleyard's conception of the significant stages in the progress of The Institution are shown by his further chapter headings, namely "The First Decade (1871–1881)," "The Transition (1881–1889)," "The Institution in being (1889–1900)," "The Pre-war Period (circa 1900–1914)," "The War Period (1914–1918)" and "The Restoration and Advance (1918–1931)."

The last of these chapters in particular has a great story of progress to tell, until it drops the curtain upon the proceedings of the Faraday Centenary celebrations in London, which appropriately link the whole with the memory of that great man of science to whose work so much of it has been due.

Following the descriptive history Mr. Appleyard has added a chapter on "The Precincts," in which the little-known but extremely interesting historical associations of the site of the Institution building are described and illustrated.

He has also included a set of photographs and short biographies of all the Presidents of The Institution up to the year 1938, as well as Appendices setting out the Royal Charter, the list of Faraday and Kelvin Lectures, Medal awards, Scholarship awards, Premiums, dates of issue of Model General Conditions of Contract and of the Institution's Wiring Regulations, and excerpts from the Ronalds Library Trust Deed. An excellent Index is preceded by a copy of the first Wiring Rules issued by The Institution in May, 1882, the direct simplicity and brevity of which must certainly earn the admiring approval of those who have criticized succeeding editions on the grounds of prolixity.

The whole volume has high value as a work of reference and is one to which all members of The Institution should have ready access. It will no doubt be followed at some future time by a further history; but there is little likelihood that the present volume will be reprinted and it will therefore in time become a rare book.

T. F. P.

INSTITUTION NOTES

ANNUAL CONVERSAZIONE

The Council have decided, in view of present conditions, to make no arrangements for the holding this year of the Annual Conversazione of The Institution.

POST-WAR PLANNING

The Council have appointed a Committee consisting of the President, the four immediate Past-Presidents, the Vice-Presidents and the Honorary Treasurer, to study the problem of post-war planning in so far as matters appertaining to electrical engineering are concerned.

BRITISH STANDARDS INSTITUTION

Mr. Johnstone Wright has been nominated by the I.E.E. Council to serve in the place of Dr. C. C. Paterson, O.B.E. (who is ineligible for re-election), as one of the representatives of The Institution on the B.S.I. Engineering Divisional Council. The Institution's other two representatives, Dr. A. P. M. Fleming, C.B.E., and Sir Thomas Purves, O.B.E., have been renominated for a further period of one year.

"THE HISTORY OF THE INSTITUTION"

"The History of The Institution," which was published in October, 1939, is a crown quarto volume containing 342 pages and 38 plates. Copies, bound in full art canvas, can be obtained by members at the specially reduced price of 12s. 6d. each (7s. 6d. in the case of Students). The price to the public is 18s. 6d. per copy.

CONTRIBUTIONS TO DISCUSSIONS

In the list of papers set out under the above heading on page 140 of the April issue the title of the paper by Messrs. A. Fairweather, M.Sc., and J. Ingham, M.Sc., should read "Subsidence Transients in Circuits containing a Non-linear Resistor, with reference to the Problem of Spark-quenching."

LOCAL CENTRE ACTIVITIES

North-Eastern Centre (and Tees-Side Sub-Centre).

On the 12th March the Faraday Lecture was delivered in Newcastle-upon-Tyne by Mr. C. E. Fairburn of the L.M.S. Railway Co. The Lord Mayor presided and he was accompanied by the Sheriff. There was a good attendance and the Lecture, the subject of which was "Electric Traction," obviously appealed to a very appreciative audience.

Two informal meetings have been held. At the first, on the 24th February, a discussion on "Impulse Testing" was introduced by Messrs. G. C. Rippon, A. Harle and G. W. B. Mitchell, whilst at the second, on the 24th March, a talk was given by Mr. R. H. Brierly entitled "A.R.P. in the Electrical Industry."

The Annual General Meeting took place on the 21st April, when the local members had the opportunity of welcoming the President and Secretary of The Institution.

Following the Annual General Meeting of the Tees-Side Sub-Centre, held on the 2nd April, Mr. T. C. Gilbert's paper entitled "Voltage-operated Earth-leakage Protection" was read and an interesting discussion resulted. Mr. H. V. Field deputized for the author, who was unable to be present.

South Midland Centre (and East Midland Sub-Centre).

At the last meeting of the session of the East Midland Sub-Centre, held at Derby on the 26th March, Mr. J. W. Gibson, M.Eng., read his paper entitled "The High-rupturing-capacity Cartridge Fuse, with special reference to Short-circuit Performance." The number of members and visitors present was 67.

In view of the difficulties of travelling and the fact that the meetings have been held in the afternoon, the Committee regard the session as having been very successful.

Northern Ireland Sub-Centre.

At the meeting on the 18th March Mr. F. R. Unwin read an informal paper entitled "Light Sources: Light and Colour," which was much appreciated on account of its historical interest and the scientific facts underlying the latest developments in the field of artificial illumination by means of the fluorescent mercury-vapour lamp. The paper was illustrated by lantern slides and practical demonstrations. The meeting was attended by members of the Electrical Contractors' Association and the Royal Society of Ulster Architects.

Mr. R. V. Macrory, of Londonderry, read an informal paper at the April meeting, entitled "Some Notes in connection with Costs of Production of Public Electric Supply in Great Britain and Northern Ireland."

ASSOCIATE MEMBERSHIP EXAMINATION: NOVEMBER, 1940 (Overseas Centres)

LISTS OF SUCCESSFUL CANDIDATES

(Success in this examination does not of itself constitute the candidate an Associate Member.)

India and Ceylon

*Parts I and II**

Battiwala, Behli Phirozeshah.
Bhakat, Bhabani Prosad.
Bhide, Jagannath Mahadeo.
Chaudhary, Mohammed Bashir.
Chowdhury, Parimal Basu Roy.
Darukhanawala, Beheram Jehangirji.
Datta, Budh Dev.
Fernando, Joseph Montagu.
Giri, K. Periyaswamy.
Gotety, Venkata Sreeramamurty.
Gupta, Bibhuti Bhusan.
Husein, Amir Ebrahim.
Iyer, S. Mahadeva.
Kesari, S.
Kingravi, Iftikhar Ahmad.
Mathuranayagam, Mailvaganam.
Nadkarni, Prabhakar Shankarrao.
Narayana Iyer, P. I.

* This list also includes candidates who are exempt from, or who have previously passed, a part of the examination and have now passed in the remaining subjects.

Parts I and II—continued

Patel, Framroze Bomanji.
Patel, Rambhai Purushottamdas.
Ramabhadran, G. N.
Ramarao, Mysore Venkatasubbarao.
Rikhy, Amolak Singh.
Sadiq, Syed Abdul.
Sankaranarayanan, P. A.
Sanmugaraja, Nadaraja.
Shroff, Adi Kaikhusroo.
Singh, Harbans.
Soloman, Aaron.
Vadgaokar, Manohar Ganpatrao.
Venkataraman, Ganapathi Iyer.

Part I only

Ahmad, Nizamuddin.
Ahmad, Zaheer.
Ansari, Mahmood.
Asadullah, S.
Athavale, Bhaskar Narayan.
Beri, Prakash Chand.
Bhullar, Sohan Singh.
Devadasan, George Samuel.
Devasirvatham, Devanason Abraham.
Doctor, Pestonji Bomonji.
Edwards, Allan Hugh William.
Gaitonde, Ganapat Ghanasham.
Ghelani, Gulamali Ratanshi.
Governor, Jamshedji Erachshaw.
Jeffereis, Charles Deryck.
Jeyanayagam, Samuel John.
Karanjia, Kaikhushru Framji
Mathur, Prakash Govind.
Mehta, Champaklal Harilal.
Mukerjee, Amitav.
Nagarkatti, Anand Shripad.
Phillips, Joseph Xavier Lucius.
Prabhakara Sarma, Yalavarthi.
Rao, Mysore Venkata Narayan.
Sen, Bansi Lal.
Thakur, Jagannath Vasudeo.
Veeraraghavan, Saranatha Iyengar.
Vincent, Savariraju Joseph.

Overseas Centres other than India and Ceylon

*Parts I and II**

Arieli, Immanuel (Palestine).
Brown, William Henry (New Zealand).
Carrier, Mervyn Joseph Alexander (Federated Malay States).
Corbett, Jack Murray (Australia).
Coxon, Herbert William (Iran).
Downes, John Godkin (Australia).
Halliday, Kenneth William Jardine (South Africa).
Jeffs, Eric Arthur (New Zealand).
Lovegrove, Richard Harris (Australia).
Maleksirat, Hassan (Iran).
Mathiesen, Eric (South Africa).
Phipps, Albert William (Buenos Aires).
Plen, Mark (South Africa).
Purchase, Harry Zander (New Zealand).
Robertson, Ronald Hislop (New Zealand).
Semmelink, Adelbert (South Africa).
Taylor-Cannon, Lewis George (New Zealand).
Withers, Bernard Tyndall (New Zealand).

Part I only

Badham, John Henry (New Zealand).
Bar-Giora, Meir (Palestine).
Barrow, Myer (South Africa).
Goodyer, Philip Alfred (South Africa).
Hodgkinson, Thomas Edwin (New Zealand).
Munro, Angus (South Africa).
Robinson, Richard Hugh Shapter (South Africa).

Part II only

Ferguson, Joseph (Australia).
Green, Eric Henry (New Zealand).
Hodgkinson, Reuben (New Zealand).
Weston, Percival Claude (New Zealand).

E.R.A. REPORTS

The Secretary has been asked by the British Electrical and Allied Industries Research Association to draw attention to the following two Reports which have recently been issued. Copies can be obtained from the Association, 15 Savoy Street, London, W.C.2, at the prices indicated.

* This list also includes candidates who are exempt from, or who have previously passed, a part of the examination and have now passed in the remaining subjects.

E.R.A. Report Ref. M/T67: Radio Interference from Thermostats in Refrigerators and Irons (By S. F. Pearce, B.Sc., and S. Whitehead, Ph.D.).

British Standard Specifications set limits to the amount of radio interference that is permissible from specified electrical appliances, including thermostats. It is well known that the measurement and treatment of the type of interference produced by thermostats present difficulties that are not yet fully resolved.

The investigation described in the present Report is a statistical survey of the "clicks" produced by typical thermostats. The work was done with a view to overcoming difficulties introduced by the dispersion of clicks.

It is concluded that the dispersion is roughly normal, though comprised of two more closely normal distributions of the makes and breaks. The dispersion is characteristic of the appliance and relatively unaffected by frequency, symmetry or suppression. The order of standard deviation is from 3 to 9 db. Various methods of applying the limits of B.S. No. 800 to practical cases are considered, including methods based on the number of readings in a consecutive sample series which exceed given limits.

The price of the Report is 4s. (postage 4d.).

E.R.A. Report Ref. M/T69: The High-Frequency Properties of Various Forms of Wire Specimens [By G. G. Sutton, B.Sc. (Eng.)].

A method is described by which the skin factor of conducting wires may be measured at frequencies of 400 Mc./s. The method, which depends upon the thermal effects of electric currents, may be applied to the measurement of high-frequency currents. Reasonable agreement with calculation is found for simple non-magnetic wires. Ferromagnetic wires are shown to have very high skin factors, but the effective permeability determined therefrom decreases with frequency, tending to a small value. The effect of longitudinal unidirectional magnetic fields upon the a.c. resistance of mumetal, already found at telephonic frequencies, has been shown to persist to very high frequencies.

The price of the Report is 6s. (postage 4d.).

BRITISH STANDARDS IN WAR TIME

The Secretary has been requested by the British Standards Institution to give publicity to the following:—

Some months before the outbreak of war the British Standards Institution, which is the recognized centre for the promulgation of all national British Standards, offered His Majesty's Government its services, as a complete unit, in the national emergency. This offer, which was sent to the Board of Trade through whom the B.S.I. receives its Government grant, was most cordially received and the various Departments of State were duly informed of the proposal.

On the outbreak of war the B.S.I. realized that its procedure in peace time was inadequate to deal effectively with the demands imposed by the changed conditions, and especially by the need for rapid action. A number of small executive committees were therefore set up for the various sections of its work, these being made fully responsible for the preparation of any war emergency Specifications the B.S.I. might be called upon to undertake. Under this

emergency procedure the executive committees were given authority to restrict the usual wide consultation of industry to those interests directly concerned, and the reduction of the time usually given for comment on draft standards. It is, of course, understood that any British Standards issued under wartime procedure will come under review directly peace returns.

Government Departments are employing the B.S.I. machinery for the preparation, co-ordination and promulgation of War Emergency Specifications to meet their several requirements, that policy being adopted because of the great experience of the B.S.I. in this field and because it provides a most effective liaison between them and almost all branches of British industry.

The B.S.I. is invited to send a representative to appropriate meetings of the Materials Committee of the Production Executive, which is representative of all Government Departments, the Central Priority Department acting as the liaison between that Committee and the B.S.I. This has brought the B.S.I. in close contact with the increasing number of Departments working to specifications, and is thereby bringing about a considerable measure of co-ordination in their preparation and issue.

As an indication of the value of the work of the B.S.I. it may be mentioned that the first issue of the War Emergency Specifications for Tins and Cans for food products and other commodities is estimated to have saved 40 000 tons of steel in the first year. The British Standards, specifically mentioned in the Government Order, have been issued with the approval of the Minister of Supply, following the recommendations of the Economy Committees set up by the Materials Committee.

The B.S.I., in collaboration with the appropriate branches of industry, has been entrusted with the task of making recommendations in the first instance to the above Economy Committees in connection with tinplate containers. The work is being extended to cover packaging generally and has involved already the formation of more than 80 committees.

A further example of the employment of the B.S.I. by the Ministry in effecting saving of material is the issue of a War Emergency Specification for Bolts and Nuts with smaller heads, which, it is estimated, will save many thousands of tons of steel a year.

Another example of the work of the B.S.I. is the rationalization of alloy and special steels. A committee under the chairmanship of Dr. W. H. Hatfield, F.R.S., has for some time past been engaged on an investigation of this complex matter and has drawn up a confidential report, which includes suggestions for a co-ordinated series of steels. Such sections of the report as can be made available to the engineering public will shortly be issued by the B.S.I., which will at the same time issue, as complementary to the above, War Emergency British Standards covering the steels recommended in the report. The Committee has most kindly placed itself at the service of the B.S.I. and is acting as its adviser in all this important work.

As a result of a conference held with the Director of Standardization, the new Ministry of Works and Buildings is using the B.S.I. as the medium for the promulgation, under its authority, of a series of War Emergency British Standards for use at the present time. Similar action will probably be taken in respect of reconstruction work.

At the request of the Ministry of Home Security a special series of specifications (about 50 in number at present) has been issued covering many aspects of A.R.P. work.

In connection with exemption from the Purchase Tax the B.S.I. has provided His Majesty's Government with definitions which give the dividing line between babies', children's, and adults' clothing, and it has made recommendations for protective boots designed for use by miners, quarrymen or moulders. Recommendations have also been made in connection with the Limitation of Supplies Order.

The experience of the B.S.I. is also being drawn upon in several directions through the good offices of the Central Priority Department, where the preparation and issue of British Standards may not necessarily follow.

Besides all this the B.S.I., in response to direct requests from industry, has prepared and issued a number of War Emergency Specifications to meet the special conditions resulting from the restriction in the supply of materials, and the demands for new and revised standards to meet these contingencies are increasing.

This war work has in no way prevented the B.S.I. from maintaining its usual close relationship with the Dominions standardizing bodies, which have been kept in close touch with these developments.

Moreover, the B.S.I. Committee in the Argentine, which is working in close collaboration with the IRAM, the Argentine national standards organization, is receiving increased recognition as its work is seen to be of real value to British export trade. British engineers and traders in the Argentine are to a greater degree giving practical support to the work of the Committee, and manufacturers in Great Britain have, by a far-sighted policy of financial support, made that work possible. British Standards, through the work of this Committee, are receiving the same consideration at the hands of the IRAM in the drawing up of Argentine standard specifications as the standards of other nations.

The B.S.I., with the help of the British Council and of industry, is also engaged in compiling a number of technical handbooks dealing with British industrial practice. The books are to be published in Spanish and Turkish and should do much to familiarize engineers and students in Turkey and the Spanish-speaking countries with British methods.

It is hoped that this brief review of the activities of the B.S.I. will be sufficient to show that the close contact maintained with the Departments of State and with industry, the confidence of both of which it so largely enjoys, is enabling the British Standards Institution to contribute in substantial measure to the national war effort.

BRITISH STANDARDS

The Secretary has been asked by the British Standards Institution to draw attention to the following new and revised specifications, copies of each of which can be obtained from the B.S.I., 28 Victoria Street, London, S.W.1, price 2s. (2s. 3d. post free).

Mains-Operated Apparatus for Radio, Acoustic and Visual Reproduction (Safety Requirements) (B.S. No. 411).

A revision of this specification has recently been issued. The revision was undertaken chiefly as a result of the

circulation, by the International Electrotechnical Commission, of a draft International Specification for safety requirements for mains-operated radio apparatus, and it has incorporated as much of the material of that draft as has proved acceptable to the interests in this country.

The scope of the British Specification is wider than that of the I.E.C. draft, for it includes television and public address equipment, but the present issue differs little in principle from the I.E.C. proposals, so that when circumstances permit of the completion of the international draft the British Standard will be fcund to be in line on all fundamental questions, though differing in some important details.

The general plan of the specification follows the lines of the previous edition, except that Section 4 has been directed more specifically to the design features of the apparatus than to its actual construction. A new Section, No. 7, has been added, dealing with the installation of the apparatus.

Vulcanized Fibre Rods and Tubes (B.S. No. 934).

The original edition of the British Standard Specification for vulcanized fibre for electrical purposes, published in 1926, covered sheets, rods and tubes. The 1936 revision dealt with sheets only, and a new specification for rods and tubes has now been issued as B.S. No. 934—1940. The specification is based on the results of comprehensive tests carried out by the Electrical Research Association on representative vulcanized fibre (natural colour) rods and tubes of quality suitable for electrical purposes. Limiting values are prescribed for various properties, and methods of test are described.

Earthing Clamps and Clips for use on Metal Pipes of Internal Diameter up to 3 inches (B.S. No. 951).

In 1938 The Institution of Civil Engineers issued some Regulations for Earthing Electrical Installations to Metal Water-pipes and Water-mains, these regulations having been drafted under the auspices of that Institution as the result of agreements arrived at between representatives of water and electrical interests.

Clause 3 of these regulations prescribes that every earth-connecting device to a water-main or water-pipe shall be of an approved design such as to ensure an efficient electrical connection. The Committee which drafted the regulations requested the B.S.I. to draw up a specification which could be taken as a basis for the approval of earth-connected devices.

This request has resulted in the issue of the present specification. The specification is based on performance rather than on mechanical design, but certain mechanical features of construction are laid down. For instance, the connection of the earthing lead to the clamp must not be made by means of the screw or screws which are themselves used for tightening the clamp to the pipe. A range of sizes has been standardized and tests for electrical resistance and for torque are prescribed. In an Appendix some notes are given on the relation between the internal and external diameters of copper, iron or lead water-pipes and steel or copper electrical conduit; from these notes the appropriate size of earthing clamp for use on any particular pipe can be ascertained.

ELECTIONS AND TRANSFERS

At the Ordinary Meeting of The Institution held on the 13th March, 1941, the following elections and transfers were effected:—

Elections

Associate Members

Alexander, John Williams.
Catherall, Frederick.
Dawson, William.
Flather, Leslie.
Knight, Alan Weir.
Konstantinowsky, Kurt, Ph.D.
Lawson, Henry.
Logan, Alexander.
Osborne, Thomas Lloyd, B.Sc.
Richardson, Alexander.
Ryall, David Scott.
Scott, Ian Alastair, Flight Lieut., R.N.Z.A.F.
Smith, Rex Challingsworth.
Tamkin, Reginald William.
Tucker, David Gordon, B.Sc. (Eng.).
Vokes, Randolph Victor.

Associates

Croft, Hyla Bert.
Cullen, Gavin Stewart.
Kirkup, Robert.
Thompson, Norman.

Graduates

Brown, Winston Herbert.
Cooper, Bobby Simeon.
Davies, William, B.Sc.
Fowler, Ivan Landen, B.Sc. (Eng.).
Gale, Donald Henry.
Gregory, William Herbert.
Houlding, Norman, B.Sc. Tech.
Isaacs, Arthur, M.Sc.
Lansley, John Robert.
Lucas, Herbert Wallace.
McFetridge, James.
Palfreman, Harry, B.Sc.
Quincey, Stanley Arthur.
Robertshaw, William Barstow.
Rochester, Henry Palethorpe.
Singh, Pal.
Washington, Noel, Pilot Officer, R.A.F.
Wilson, John.
Woithe, William Henry, B.E.
Wood, William Stanley.

Students

Acomb, John Mountain.
Adams, Dennis Arthur J.
Arnold, Rhodes Horatio P.
Bache, Harry.
Ball, Sidney Arthur.
Barnard, Joseph William.
Benbow, George Lewis.
Benn, Gordon.
Bennett, Raymond George.
Blythe, John Percival.
Boggis, Robert John.
Bowers, Stanley Howard.
Braganza, Joseph Vincent P.
Broster, Noel Leonard.
Cagney, Desmond Noel.
Chatt, Douglas Frederick.
Cheseldine, Ian Harold.
Cheshire, Charles Gordon.
Clarke, Francis John.
Clarke, William Kenneth B.
Conn, Robert Bainbridge.
Cork, Herbert Frederick.
Critchley, Octavius Hunt.
Cusworth, William Frederick.
Dalgleish, Edward Gordon.
Davies, Arthur Leonard.
Dunn, Geoffrey John.
Eggs, James Edward.
Fedida, Samuel.
Fenwick, William Henry.
Fishley, Arthur George M.
Fletcher, Maurice John.
French, Robert Glenwright.
Frisby, Robert.
Gee, Fred.
Golden, Maurice Alfred.
Goswami, Roshan Lall N.
Hardman, Frank Reginald.
Hewitt, David Charles.
Hibbert, Christopher Albert.
Hilton, Frank.
Hutt, Albert Douglas.
Johnson, James Bernard.
Jones, John William.
Jones, Leslie Edwards.
Krishnan, Subramania.
Lamb, John.
Lang, Frank Gordon.
Lawson, Robert.
Leece, Ronald.
Leslie, Frank Marsden.
Lewis, Geoffrey George E.
Limaye, Laxman Vishwambhar.
Little, Donald.
Lyndon, Stewart Edward.
McCallum, Donald Murdo.
McCleery, James Alexander.
Macdiarmid, Ian Ferguson.
McIlwrick, Keith Nicholls.
Maclaren, Brian Douglas F., B.A.
Martin, Robert Edgar.
Mehrotra, Raja Krishna, B.Sc.
Mole, John Pattison.
Morton, Charles Howard.
Munby, James White.
Naha, Dakshina Ranjan.
Naidu, B. Sadagopa.
Plow, Royston Samuel S.
Plummer, Keith Mark.
Pollard, George William.
Prabhu, N. Divaker.
Prescott, Frank Cecil.
Ray, Chuni Lal.
Rhoden, Leslie.
Ross, Samuel White.
Saulez, Kenneth John.
Shah, Bhupendraray Dharamchand.
Sharp, William.

Students—continued

Simpson, Eric William.
Smith, Max Chambers.
Spencer, Eric.
Spencer, Herbert James C.
Stober, John Williamson.
Stokoe, James Ord.
Stone, Allan Bertram.
Subramaniam, Sitarama.
Sutton, Maurice George.
Tanner, Joseph Alan.
Taylor, Derrick Ronald.
Taylor, James.
Thomas, Robert Geoffrey.
Tiley, Ronald Leslie.
Trainer, Allan Atkinson.
Turner, Peter Frederick.
Vercoe, Henry Frank.
Ward, Frederick Roy.
Wells, Charles William.
Whitaker, Philip.
Whitehouse, William Thomas.
Williams, Mervyn Brynmor.
Wise, Rex George.
Wood, William Henry.

Transfers

Associate Member to Member

Bentham, Harold.
Clegg, Percy, B.Sc.Tech.
Hughes, Richard Leslie, B.Sc.
Tuson, Kenneth Hadley.
Williams, David Ronald, B.Sc.

Associate to Associate Member

Appleby, John Harry.
Byng, Frederick.
Featherstone, William Arthur E., Flight Lieut., R.A.F.
Gleaves, Leonard Cecil.
Griffiths, Thomas Daniel.
Humphreys, Harold Victor, Lieut. R.E.
Lewis, David.

Graduate to Associate Member

Aleong, Rupert Vernon S.
Anderson, Ian Lind.
Armstrong, Ronald William.
Bartlett, Frederick William G.
Beal, George.
Biddle, Gordon.
Blacklaws, Alexander Bothwell.
Collinson, William.
Cottrell, Seymour.
Coysh, James William.
Dark, Cyril Montague.
Hafiz, Ahmad Adnan, Major, B.Sc.(Eng.).
Hopkinson, Alexander Forsyth.
James, Arthur Jack T.
Lodge, Edwin Faville.
Morton, James Dickie, B.Sc.
Murland, James Robert W., Capt., B.Sc.(Eng.).
Oldhams, Arthur Stanley.
Phillips, Charles James.
Priestley, Henry Thomas.
Robertson, William.
Robinson, William, B.Sc. (Tech.).
Snowdon, John Walter, B.Sc. (Eng.).
Taylor, Charles Ronald, B.Sc.
Turner, William Aylmer L., B.A.
Uhl, Arthur Henry.
Vaughan, Montague.
Wakefield, John Albert P.
Watson, Norman, B.Sc.
Whitaker, Evald Mattievich, B.Sc.
Williams, William Lloyd.
Zainal, Raja Sulaiman.

Student to Associate Member

Trainor, Hugh Martyn, B.Sc.(Eng.).

Student to Associate

Kapus, Erwin Esteban, B.Sc.(Eng.).

At the Ordinary Meeting of The Institution held on the 3rd April, 1941, the following elections and transfers were effected:—

Elections

Associate Members

Boyd, Arthur William, B.Sc.
Cleary, Edmond Valentine, B.E.
Coker, Oluwaji Oladotun, B.Sc.
Dickinson, Robert Bigland.
Dunkley, Leslie William, Capt., R. Signals.
Gheury de Bray, Maurice Edmond J.
Hipwell, Lewis William.
Knowles, William.
Lunnon, Ronald David.
Pegler, Geoffrey David, Major, R.A.O.C., M.Sc.
Powell, Edward William H.

Associates

Beardmore, Harry.
Collis, Cyril George.
Todd, William.

Graduates

Adams, Arthur Stanhope, B.Sc.(Eng.).
Foster, George Edward.
Rushton, Edmund George.
Suggate, Jack, B.Sc.(Eng.).

Students

Asquith, Stanley Francis W.
Atcherley, Victor Clive.
Bailey, Alan Capey.
Birks, Harold.
Brown, Kenneth Robert.
Burrell, John Gill.
Cale, Patrick Reginald.
Campbell, Kenneth Arthur.
Carter, Walter George.
Charania, Alibhoy Purushottam.
Cook, John Alexander.
Davies, Hugh Bennett.
Dickinson, Alan Corbridge.
Dobson, Eric.
Downham, Guy Bullock.
Dunsmuir, Robert.
Elliott, George Francis.
Evans, John Michael T.
French, Charles.
Fricker, Harry.
Gangji, Badrudin Karmali.
Gatfield, Alfred Charles, B.Sc.
Gould, Norman George.
Grundy, Alan Herbert.
Haggarty, John Michael.
Halder, Asoke Ranjan.
Hales, Arthur Charles.
Hastings, Gerald.
Henniker, William Brian.
Hillan, Arthur Bernard.
Holden, Thomas Lindsay.
Holme, Edward.
Hosey, William Edward.
Hsu, Kwoh-Chang.
Hyett, Noel Francis.
Iyengar, K. R. Krishnaswamy, B.Sc.
Iyer, Y. V. Bhaskar.
Jack, David Simpson.
Johnson, David Robert G.
Kirk, Herbert Peter.
Laird, Walter William.
Leach, Norman.
Levy, Isaac Oscar.
Lewis, Frederick William F.
Lewis, Stanley Harry.
Lipscombe, Roynon Albert H.
Lofty, Arthur Douglas.
Lyon, Arthur Anderson.
MacArthur, Daniel, B.Sc.
McCracken, William.
McDonald, Duncan.
Macintyre, William Angus.
Marston, Arthur Edward.
Meadowcroft, Alban James.
Miller, Ernest William.
Nash, Frank Joseph, B.Sc.
Orton, David Leyland.
Palfreman, Eric Gordon.
Paranjape, Bhalchandra Narayan, B.Sc.
Parris, Leslie Francis.
Rhodes, Eric.
Sardana, Munishwar Nath.
Saunders, Donald Roy.
Saunders, Thomas Alfred.
Seall, Dennis Edward.
Shrikant, Ranbir Singh.
Singh, Jagir, B.A.
Smyth, Laurence Francis.
Sreenivasa Rao, Bhupathipalli.
Starr, Kenneth Donald.
Stephenson, Sydney Kenneth.
Stout, John Ellis.
Sykes, Harry.
Taylor, Wilfred.
Tomey, Leon Walter.
Ullyatt, Christopher.
Wade, George Moore.
Wade, Peter Kenneth.
Wallis, Albert Roy.
Watmough, Ernest Edward.
Williams, Owen Griffith, B.Sc.
Wood, John Henry.
Woodall, Robert Henry.

Transfers

Associate Member to Member

Brown, David Gregory, B.Sc.
Thomas, Thomas Rees, B.Sc.

Associate to Associate Member

Hall, William.
Hounsell, Ernest Alfred.
Speirs, Robert.

Graduate to Associate Member

Allan, Alexander Frederick G.
Byrne, Reginald Wingate C.
Conning, James.
Cover, William.
Crew, William Stephen.
Davies, Henry.
Dudley, Clarence Richard.
Fitzmaurice, John Cornelius.
Floyd, Geoffrey.
Furber, Harold Darrel.
Gauntlett, John Richard.
Hammerton, Thomas Gordon, B.Sc., Ph.D.
Hewitson, Harry Bleamire.
Jeffs, Albert Lee, B.Sc.(Eng.).
Kendall, Michael Ward, Major, R.A.O.C.
Lochhead, Ian Ferguson, B.Sc.
McDonald, Alexander.
Pettifor, Percy Hayward, B.Sc. (Eng.).
Picken, Donald Allsopp.
Richards, Frederick Harry A.
Robertson, Harold.
Scott, Robert, B.Sc.
Shepherd, Edward William.
Smith, John Watson.
Supper, Jesse Bertram.
Tuffnell, Reginald Charles.
Weaver, Edward William.
Wooldridge, John Leonard, B.Sc.(Eng.).

Student to Associate Member
Stevenson, Hugh Craig, B.Sc.

The following transfers were also effected by the Council at their meeting held on the 13th March, 1941:—

Student to Graduate

Bhide, Ramachandra Dattatray.
Collins, John Henry.
Dingwall, Norman Pirie.
Gillanders, Kenneth Henry.
Hamilton, David.
Harper, William Glass W.
Huey, Eustace Beresford, Sub-Lieut., R.N.V.R.
Palmer, Francis Charles W.
Parke, Edward Gaymer.
Sussmann, Milo.
Taylor, William Geoffrey, B.Sc.(Eng.).

ACCESSIONS TO THE LIBRARY

[NOTE.—(*) denotes that the book is also in the Lending Library. The books cannot be purchased at The Institution: the names of the publishers and the prices are given only for the convenience of members.]

BURNHAM, T. H., and HOSKINS, G. O. Engineering economics. 5th ed. 2 vol. 8vo. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 10*s.* 6*d.* *each vol.* (*)

Book I, Elements of industrial organization. By T. H. B. and G. O. H. vii + 322 pp.
Book II, Work organization and management. By T. H. B. xii + 375 pp.
To introduce the engineer to a study of the economic system—the system of production and distribution—and to provide in convenient form an introduction to the reading required for Section A (Fundamentals of Industrial Administration) of the examination of The Institution of Mechanical Engineers, for the Graduate examination of The Institution of Production Engineers and for the optional subject in the syllabus for the Associate Membership examination of The Institution of Electrical Engineers.

BUTLER, J. A. V., *D.Sc.* Electrocapillarity. The chemistry and physics of electrodes and other charged surfaces. 8vo. viii + 208 pp. (London: Methuen and Co., Ltd., 1940.) 12*s.* 6*d.* (*)

The book deals with potential differences at electrified interfaces, the origin and nature of the effects that arise therefrom, and with electrode equilibria and kinetics.

CAMM, F. J. Radio engineer's pocket book. sm. 8vo. 147 pp. (London: George Newnes, Ltd., 1940.) 3*s.* 6*d.*

CHAMPION, F. C., *M.A.*, *Ph.D.* University physics. pt. 2, Heat. 8vo. 148 pp. (London: Blackie and Son, Ltd., 1940.) 5*s.* 6*d.* (*)

Primarily intended for students taking a First and Second Year Course in Physics at a University and designed for preparation for examinations of the standard of part I of the Natural Science Tripos at Cambridge, the B.Sc. General Degree of London, etc.

CHAPMAN, S., and BARTELS, J. Geomagnetism. 2 vol. 8vo. (Oxford: Clarendon Press, 1940.) 63*s.*

vol. 1, Geomagnetism and related phenomena. xxviii + 542 pp.
vol. 2, Analysis of the data, and physical theories. x + 543–1049 pp.

CRELLIN, E. A. Hydroelectric power stations. sm. 8vo. iv + 74 pp. (Scranton, Pa.: International Textbook Co., 1935.) 8*s.* (*)

A general, non-mathematical survey of the subject.

CROSS, H. H. U. Modern ignition simply explained. Construction, maintenance, and light repairs; an exposition of principles, and illuminated by reference to the leading types of ignition devices. 2nd ed. sm. 8vo. v + 144 pp. (London: The Technical Press Ltd., 1940.) 5*s.* (*)

FAWCETT, J. R. Designing for mass production: an introduction. 8vo. ix + 141 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1939.) 10*s.* 6*d.* (*)

The author has endeavoured to outline all that is essential for those interested in mass-produced products including the principles of the new manufacturing technique.

FRANCIS, W. Boiler house and power station chemistry. 8vo. xii + 203 pp. (London: Edward Arnold and Co., 1940.) 15*s.* (*)

On the general chemical aspects of the combustion of coal and the industrial chemistry of water and oil, describing analytical methods and related matter.

GAFFERT, G. A., *Sc.D.* Steam power stations. 2nd ed. 8vo. xii + 592 pp. (New York; London: McGraw-Hill Publishing Co., Ltd., 1940.) 31*s.* 6*d.* (*)

The method has been to present, in order, construction, performance characteristics, and the integration of major and minor machinery. Sections on costs, load curves, plant location and station design are included.

GOLDING, E. W., *M.Sc.Tech.* Electrical measurements and measuring instruments. A textbook covering the syllabuses of the B.Sc. Engineering, City and Guilds (Final), and I.E.E. examinations in this subject. 3rd ed. 8vo. xii + 828 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 21*s.* (*)

Additions have been made relating to the Giorgi (M.K.S.) system of units, new methods of magnetic testing, of current transformer testing, and the requirements of the Electricity Supply (Meters) Act, 1936.

GRAY, A., *M.Sc.* Principles and practice of electrical engineering. 5th ed., revised by G. A. Wallace. 8vo. xiii + 586 pp. (New York; London: McGraw-Hill Publishing Co., Ltd., 1940.) 28*s.* (*)

A thorough revision of the work, but no fundamental change in its character. Special mention may be made of the treatment of the induction motor, wattmeter, induction voltage regulator, direct current starting boxes and speed control, self-excitation, armature reaction in d.c. machines, transients, and thermionic-tube amplifiers.

HARTSHORN, L., *D.Sc.* Radio-frequency measurements by bridge and resonance methods. 8vo. xv + 265 pp. (London: Chapman and Hall, Ltd., 1940.) 21*s.* (*)

Volume 10 of a series of monographs on electrical engineering edited by H. P. Young. This is a practical work divided into three main sections: Principles, Apparatus and Methods.

HARVEY, A. F., *D.Phil.* Thermionic tubes at very high frequencies. With a foreword by E. B. Moullin. 8vo. xii + 234 pp. (London: Chapman and Hall, Ltd., 1941.) 18*s.* (*)

On the general properties of thermionic tubes employed in ultra-high-frequency work, the retarding field generator, the magnetron; also an outline of velocity modulation tubes, the Klystron and allied tubes and wave guides and horn radiators.

HEIGH, W. The practice of arc welding. With a foreword by J. D. Anderson. sm. 8vo. ix + 114 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 5*s.* (*)

The practice of welding from the point of view of the artisan.

HUGHES, G. B. Dry batteries: how to make them. sm. 8vo. 160 pp. (London: Hutchinson's Scientific and Technical Publications, 1940.) 6*s.* (*)

JAUNCEY, G. E. M., *D.Sc.*, and LANGSDORF, A. L. M.K.S. units and dimensions and a proposed M.K.O.S. system. 8vo. viii + 62 pp. (New York: The Macmillan Co., 1940.) 4*s.*

The purposes of this little book are to acquaint engineers, physicists, and teachers and students of electrical engineering and physics with the properties of the new metre-kilogram-second (M.K.S.) system of basic units . . . to describe a fourth basic unit (a question left open by the I.E.C. in 1935); to describe a proposed M.K.O.S. system of basic units; and to discuss the difference between magnetic flux density (B) and magnetic field strength (H).

JEANS, *Sir* J., *O.M.*, *F.R.S.* An introduction to the kinetic theory of gases. 8vo. 311 pp. (Cambridge: University Press, 1940.) 15*s.* (*)

This work covers a good deal of the same ground as the author's earlier book "The dynamical theory of gases," but in a simpler and more physical manner, and is intended to provide such knowledge of the kinetic theory as is required by the average serious student of physics and physical chemistry.

KAPP, R. O. Science versus materialism. 8vo. vi + 280 pp. (London: Methuen and Co., Ltd., 1940.) (*)

This book is an attempt to solve, in a way which any interested layman can understand, a problem which has been hotly debated through the centuries: Is Matter the only reality?

KUHLMANN, J. H. Design of electrical apparatus. 2nd ed. xiv + 506 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1940.) 30*s*. (*)

On the theory and procedure of design of d.c. machines, synchronous machines, induction motors and transformers.

LANCHESTER, F. W., *LL.D.*, *F.R.S.* Lanchester's "potted logs." Parts I and II. sm. 8vo. 27 pp. (London: Taylor and Francis, Ltd., 1939.) 2*s*.

LANGMAN, H. R. How to make working diagram models, illustrating electrical principles. sm. 8vo. viii+73 pp. (London: The Technical Press, Ltd., 1939.) 3*s*. 6*d*. (*)

LAWS, W., *M.Sc*. Electricity applied to marine engineering. sm. 8vo. 276 pp. (London: The Institute of Marine Engineers, 1940.) 5*s*. 6*d*. (*)

A book for students of marine engineering who are preparing for the Second- and First-Class Board of Trade Examinations.

LEVY, H., *D.Sc.*, *M.A.* Modern science. A study of physical science in the world today. 8vo. x+736 pp. (London: Hamish Hamilton, 1939.) 21*s*. (*)

The story of the evolution of science for the ordinary intelligent reader and of the part mathematics has played in the development of modern physics.

LEWIS, E. J. G. Radio receiver servicing and maintenance. 2nd ed. sm. 8vo. xi + 231 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1938.) 8*s*. 6*d*. (*)

LLEWELLYN, F. B. Electron-inertia effects. Cambridge Physical Tracts. 8vo. x + 104 pp. (Cambridge University Press, 1941.) 7*s*. 6*d*. (*)

A transient picture of the rapidly changing progress in electron-inertia effects. The author is associated with the Bell Telephone Laboratories, Inc.

LOEB, L. B. Fundamental processes of electrical discharge in gases. 8vo. xviii + 717 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1939.) 42*s*.

The object of this work is to link the classical discharge theory of textbooks and monographs with recent experimental developments.

LYTHALL, R. T. Calculation of fault currents in electrical networks. Circuit-breaker selection. 8vo. vii+72 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 8*s*. 6*d*. (*)

The present work attempts to set out in simple language the methods of conducting calculations in a form easily understood and presents them in such a way that they may be immediately applied without recourse to deep theory.

—— The J. and P. switchgear book; being an outline of modern switchgear practice for the non-specialist user. 3rd ed. vol. 1. vii + 431 pp. (London: Johnson and Phillips, Ltd., 1939.)

MABY, J. C., and FRANKLIN, T. B., *M.A.* The physics of the divining rod. Being an account of an experimental investigation of water and mineral divining. 8vo. xv + 452 pp. (London: G. Bell and Sons, Ltd., 1939.) 21*s*.

MAGNUSSON, C. E., *M.S.*, *Ph.D.* Alternating currents. 5th ed. 8vo. xvii + 721 pp. (New York; London: McGraw-Hill Publishing Co., Ltd., 1939.) 30*s*. (*)

The book presents the basic principles of alternating currents and their application to electric power engineering under present-day conditions.

MANTELL, C. L., *Ph.D.* Industrial electrochemistry. 2nd ed. 8vo. x + 656 pp. (New York; London: McGraw-Hill Publishing Co., Ltd., 1940.) 38*s*. (*)

Broadly inclusive of the theoretical and technical sides of electrochemistry, the aqueous and fused electrolyte industries, electrothermics (furnaces), and the electrochemistry of gases, as well as the distinctly engineering aspects.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY. Electric circuits. A first course in circuit analysis for electrical engineers. By members of the Staff of the Department of Electrical Engineering, M.I. of T. 8vo. xxxiii + 782 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1940.) 45*s*. (*)

The first volume of a new series which will present substantially as a unit a revision of the basic technological principles of electrical engineering. The present volume is a comprehensive work on alternating-current theory including transient analysis, theory of symmetrical components, etc.

MAVOR, S. Memories of people and places. 8vo. 327 pp. (London: William Hodge and Co., Ltd., 1940.) 10*s*. 6*d*. (*)

MILLER, D. C., *D.Sc.*, *D.Eng.*, *LL.D.* Sparks, lightning, and cosmic rays. Christmas week lectures for young people, 1937, The Franklin Institute. 8vo. xvii + 192 pp. (New York: The Macmillan Co., 1939.) $2.50 (*)

MILLIKAN, R. A. Cosmic rays. Three lectures, 1936–7. 8vo. viii + 134 pp. (Cambridge: University Press, 1939.) 8*s*. 6*d*. (*)

On the discovery of cosmic rays and its general significance, super-power particles, and the earth's magnetic field and cosmic-ray energies.

MOLESWORTH, *Sir* G. L., *K.C.I.E.* Pocket-book of useful formulae and memoranda for civil and mechanical engineers. 31st ed., ed. by A. P. Thurston. sm. 8vo. 955 pp. (London: E. & F. N. Spon, Ltd., 1940.) 7*s*. 6*d*.

MOLLOY, E., *general editor*. Electric wiring (domestic). A practical work for installation engineers, contractors and electric wiremen. 8vo. viii + 240 pp. (London: George Newnes, Ltd., 1940.) 5*s*. (*)

—— Installation and maintenance of electric motors. A practical treatise for installation engineers, plant engineers and works electricians. 8vo. viii + 180 pp. (London: George Newnes, Ltd., 1940.) 5*s*. (*)

—— Practical design of small motors and transformers. Explaining the practical methods to be employed in designing and constructing small electric motors and small power transformers. 8vo. viii + 176 pp. (London: George Newnes, Ltd., 1940.) 5*s*. (*)

MORLEY, A., *O.B.E.*, *D.Sc.*, and HUGHES, E., *Ph.D.*, *D.Sc.* Electrical engineering science. A second-year course. sm. 8vo. ix + 256 pp. (London: Longmans, Green and Co., Ltd., 1940.) 4*s*. 6*d*. (*)

MOTT, N. F., and GURNEY, R. W. Electronic processes in ionic crystals. 8vo. xii + 275 pp. (Oxford: Clarendon Press, 1940.) 20*s*. (*)

A study of the conduction of electricity in ionic crystals from the points of view of (1) the behaviour of electrons in metals and (2) the properties of ions in solutions.

MURRAY, D., *M.A.* The philosophy of power. [vol. 1], First principles. 8vo. 336 pp. (London: Williams and Norgate, Ltd., 1939.) 12*s*. 6*d*. (*)

"This is the first of several volumes, which may be described as bringing the philosophy of Herbert Spencer up to date; but it concentrates, as Spencerian philosophy does not, on human welfare, particularly the feeding and breeding of men."

NEUMANN, R. Symmetrical component analysis of unsymmetrical systems. x + 219 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1939.) 21*s*. (*)

An attempt to fill the gap between short elementary treatments and the more voluminous books on this subject. Not more than an elementary knowledge of trigonometry and calculus is required for the understanding of the mathematical sections.

OLSON, H. F., *Ph.D.* Elements of acoustical engineering. 8vo. xv + 344 pp. (London: Chapman and Hall, Ltd., 1940.) 30*s*. (*)

This book is the subject matter of thirty lectures at Columbia University. It is an exposition of the fundamental principles used in modern acoustics and a description of the existing acoustical instruments.

PARSONS, R. H. The early days of the power station industry. 8vo. x + 217 pp. (Printed for Babcock and Wilcox, Ltd., at the University Press, Cambridge, 1939.) 15*s*. (*)

The history of electricity supply, covering mainly the last two decades of the 19th century.

PLATT, M., *M.Eng.* Elements of automobile engineering. A general introduction to automobile engineering for students. sm. 8vo. vii + 192 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 5*s*. (*)

PLEDGE, H. T. Science since 1500. A short history of mathematics, physics, chemistry, biology. Board of Education—Science Museum. 8vo. 357 pp. (London: H.M. Stationery Office, 1939.) 7*s*. 6*d*. (*)

PYE, D. R., *C.B.*, *Sc.D.*, *F.R.S.* The internal combustion engine. 2nd ed. vol. 1. 8vo. xv + 294 pp. (Oxford: Clarendon Press, 1937.) 15*s*. (*)

Although dealing with principles rather than practice, the book aims, nevertheless, at giving the groundwork of a practical knowledge of the subject.

RADLEY, J. A., *M.Sc.*, and GRANT, J., *Ph.D.*, *M.Sc.* Fluorescence analysis in ultra-violet light. 3rd ed. 8vo. xvi + 424 pp. (London: Chapman and Hall, Ltd., 1939.) 22*s*. 6*d*. (*)

The first part of this work outlines the theory and technique of fluorescence analysis and the second and main part deals with its many applications. A comprehensive bibliography is included.

RAILWAY SIGNALLING. Railway signalling and communications: installation and maintenance. 8vo. xv + 416 pp. 8vo. (London: The St. Margaret's Technical Press, Ltd., 1941.) 8*s*. (*)

A publication adapted to the needs of the lineman, installer, inspector, etc. Based on lectures to the staff of the Signal and Telegraph Department, L.N.E. Railway, and edited and prepared for publication by A. E. Tattersall and T. S. Lascelles.

RAPSON, E. T. A., *M.Sc.(Eng.)*. Experimental radio engineering. By E. T. A. R. assisted by E. G. Ackermann. 8vo. viii + 142 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 8*s*. 6*d*. (*)

A number of experiments and methods of measurement suitable for a three or four years' course in radio engineering are set out. The work is the outcome of the development of instructional courses for students engaged in the radio industry.

—— Problems in radio engineering. 4th ed. sm. 8vo. viii + 123 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1939.) 3*s*. 6*d*. (*)

These problems were collected to facilitate the class-work in radio engineering, which forms part of the course for the Higher National Certificate in Electrical Engineering, and are drawn from past examination papers of the City and Guilds of London Institute in Radio Communication, the I.E.E. in Electrical Communications, and the University of London in Telegraphy and Telephony.

REYNER, J. H. Cathode-ray oscillographs. sm. 8vo. viii + 177 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1939.) 8*s*. 6*d*. (*)

A simple book dealing with the practical application of cathode-ray tubes. Tube design is not dealt with, but the work provides detailed groundwork of the theory underlying the circuits and is of interest to all who have occasion to use cathode-ray equipment.

REYNER, J. H. Modern radio communication. A manual of modern theory and practice, covering the syllabus of the City and Guilds examination and suitable for candidates for the P.M.G. Certificate. With a foreword by G. W. O. Howe. vol. 1. 7th ed. sm. 8vo. xiii + 334 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1939.) 5*s*.

—— Short-wave radio. 2nd ed. sm. 8vo. xviii + 177 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1939.) 10*s*. 6*d*. (*)

An attempt to present a non-mathematical résumé of the subject, but a sound knowledge of ordinary radio technique is essential to a proper understanding of short-wave phenomena and this has been assumed to a great extent.

RICHARDS, E. L. Diesel engines and Diesel electric power. A complete practical book of instruction on Diesel engines, their construction, principles, operation, care and adjustment; operation and care of electrical power equipment in connection with Diesel engines. 8vo. 309 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 10*s*. 6*d*. (*)

RICHARDSON, E. G., *Ph.D.*, *D.Sc.* Sound. A physical text-book. 3rd ed. 8vo. vii + 339 pp. (London: E. Arnold and Co., 1940.) 16*s*. (*)

In this edition the chapters on impedance, supersonics and sound reproduction have been extended and brought up to date.

RISSIK, H. The fundamental theory of arc convertors. With a foreword by C. L. Fortescue. 8vo. xv + 287 pp. (London: Chapman and Hall, Ltd., 1939.) 18*s*. (*)

To introduce the general principles of current conversion by means of arc discharge devices to the electrical engineer interested primarily in the circuit design of commercial arc convertors, whether of the mercury-arc, hot-cathode, or atmospheric-arc types.

SAND, H. J. S., *D.Sc.*, *Ph.D.* Electrochemistry and electrochemical analysis. A theoretical and practical treatise for students and analysts. 2 vol. sm. 8vo. (London: Blackie and Son, Ltd., 1939–40.) (*)

vol. 1, Electrochemical theory. viii + 133 pp. 4*s*. 6*d*.
vol. 2, Gravimetric electrolytic analysis and electrolytic Marsh test ix + 149 pp. 5*s*.

SANFORD, F. Electric distribution fundamentals. 8vo. viii + 237 pp. (New York; London: McGraw-Hill Book Co., Inc., 1940.) 16*s*. 6*d*. (*)

A practical work for junior electrical engineers whose knowledge of mathematics is limited.

SHOLL, W. S. The dry battery. A practical manual, including battery manufacture. sm. 8vo. vii + 75 pp. (London: C. Griffin and Co., Ltd., 1940.) 2*s*. 6*d*. (*)

"Addressed to the reader who desires to obtain satisfactory results in the manufacture of dry batteries with a minimum of theory and the least expenditure of time and money."

SINGLETON-GREEN, J., *M.Sc.* Concrete engineering. 2 vol. sm. 8vo. (London: C. Griffin and Co., Ltd., 1933–35.) (*)

vol. 1, Practical concrete. viii + 258 pp. 8*s*.
vol. 2, Properties of concrete. x + 261 pp. 8*s*.

SMYTH, H. D., and UFFORD, C. W. Matter, motion, and electricity. A modern approach to general physics. 8vo. xiii + 648 pp. (New York; London: McGraw-Hill Book Co., Inc., 1939.) 26*s*. (*)

The approach to the subjects is based on the developments of atomic physics in the last forty years and the M.K.S. system of units has been adopted.

PROCEEDINGS OF THE INSTITUTION

963RD ORDINARY MEETING, 20TH FEBRUARY, 1941

Mr. J. R. Beard, M.Sc., President, took the chair at 12.30 p.m.

The minutes of the Ordinary Meeting held on the 30th January, 1941, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

Messrs. R. A. McMahon and H. L. D. Wyman were appointed scrutineers of the ballot for the election and transfer of members, and after the scrutiny the President announced that the members whose names appeared on the list (*see* Institution Notes in the April issue of Part I, page 146) had been duly elected and transferred.

The meeting then terminated.

964TH ORDINARY MEETING, 13TH MARCH, 1941

Mr. J. R. Beard, M.Sc., President, took the chair at 12.30 p.m.

The minutes of the Ordinary Meeting held on the 20th February, 1941, were taken as read and were confirmed and signed.

Messrs. P. F. Hart and P. Honey were appointed scrutineers of the ballot for the election and transfer of members, and after the scrutiny the President announced that the members whose names appeared on the list (*see* Institution Notes, page 173) had been duly elected and transferred.

The President also announced that during the months of January and February 5 006 donations and subscriptions to the Benevolent Fund had been received, amounting to £2 356. A vote of thanks was accorded to the donors.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The meeting then terminated.

965TH ORDINARY MEETING, 3RD APRIL, 1941

Mr. J. R. Beard, M.Sc., President, took the chair at 12.30 p.m.

The minutes of the Ordinary Meeting held on the 13th March, 1941, were taken as read and were confirmed and signed.

Messrs. E. A. Guthrie and A. Middleton were appointed scrutineers of the ballot for the election and transfer of members, and after the scrutiny the President announced that the members whose names appeared on the list (*see* Institution Notes, page 174), had been duly elected and transferred.

Messrs. P. K. Davis, F. Pooley and A. E. Quenzer were appointed scrutineers of the ballot, if necessary, for the election of new Members of Council.

The President announced that during March 481 donations and subscriptions to the Benevolent Fund had been received, amounting to £199. A vote of thanks was accorded to the donors.

The meeting then terminated.

ELECTRICAL INSULATING MATERIALS*

By Dr. G. E. HAEFELY, Associate Member.

INTRODUCTION

In preparing this first review of progress on electrical insulating materials as a whole, I have confined myself, in the case of the older and established materials, to outstanding improvements made during the last 10 years and have dealt in more detail with new dielectrics recently developed but not necessarily fully exploited by the electrical industry. The order of the materials reviewed follows generally that adopted for the classification in Warren's book on "Electrical Insulating Materials" published in 1931, a treatise presenting in the most thorough manner the status of electrical insulating materials up to that time. The past decade has been a period of intensive research for the perfecting of existing insulating materials, in order to meet the ever-increasing requirements resulting from the further expansion of electricity—in generation, transmission and utilization. New materials had to be found to ensure greater reliability of service for those branches of the electrical industry which were mainly developed during recent years, such as automatic telephony, radio and television. In this unusual time of war no efforts are spared to combine the research activities of all the different industries for the common purpose of maintaining output and the leading position which the country's products have secured in the world market. Close co-operation between the electrical engineer, the physicist and the chemist, has resulted in the creation of new insulating materials without which many of the electrical industry's more recent achievements could not have been attained in so short a time. The knowledge now accessible to the chemist enables him to use such elementary raw materials as coal, lime, water and cellulose, which are available in unlimited quantities, to make new substances almost to a predetermined specification of properties.

Mention should here be made that the ever-growing activities of the British Electrical and Allied Industries Research Association have helped very substantially in the development of new insulating materials. Its engineers and scientists have reviewed and improved methods of testing, have pointed the way for bettering existing materials, and have provided physical and chemical bases for the investigation of new materials. Many specifications have been drawn up to guide the industry in the testing and application of materials, and many more are in course of preparation.

NATURAL MINERAL INSULATIONS

Beginning the review of the progress on dielectrics in general, it should be recorded that mica, used for more than 60 years, is still to-day the most important because of its high degree of reliability in service under the most severe conditions—atmospheric, thermal and physical. Analytical chemists have long felt that it should be possible to make mica synthetically, but only recently has a certain measure of success been achieved in an American laboratory in producing experimentally a sheet material with properties approaching those of natural mica. However, until the stage has been reached when synthetically-produced mica can compete in quality and price with the natural material, which has taken millions of years to form, the natives of India and the other countries of origin will continue in much the same way as hitherto to mine the mineral. It is particularly fortunate at the present time of international disturbances that this country, together with America, controls the main market for this important material.

As is well known, mica is chiefly used in the electrical industry as micanite, which consists of mica splittings bonded together and further treated. Micanite in various forms still constitutes the main insulation in rotating machinery, particularly generating plant and heavy-duty traction motors. Micanite, once used extensively for the insulation of transformer windings and later replaced by cheaper and more adaptable materials, has recently once again proved its outstanding suitability for this purpose when found to be the only satisfactory insulation for the transformer windings for the extraordinarily high voltage of 280 kV chosen for the Boulder Dam electrification scheme. Built-up mica is unquestionably still the most suitable material for the insulation of commutators, and modern heating appliances where flexible insulation is required are preferably insulated with mica or micanite. During the last 10 years there have been no fundamental changes in the technique of micanite manufacture, but developments in the direction of more rapid production of material in larger quantities continue, and progress in respect of greater uniformity of the material is very noticeable. The micanite materials of the present day are very largely mechanically built and the methods and systems of control are such that, in spite of mass production, the composition, dimensions and properties are more uniform than was the case with hand-built material. Micanite suitable for punching had to be developed, this method being more and more used for commutator separators for fractional-horse-power motors, automobile starting motors and dynamos, and for similar machines with small commutators. Uniformity of the micanite and very accurate thickness are essential for this class of work, and the high standard of this material has resulted in its increasing use in place of mica, it being also easier and more economical to handle. The end rings for these small commutators are also produced by automatic presses with a high degree of accuracy. Apart from commutator insulation, winding strips and cover plates in electric irons, strips for regu-

* A review of progress.

lators, rheostats and similar apparatus, washers and plates of various shapes and sizes are manufactured by punching heat-resisting micanite.

Micafolium is still used for its original purpose, but special adhesives have been developed in order to meet modern specifications of low dielectric losses at elevated temperatures. In recent years mica tape has been increasingly used in place of micafolium because of its higher mica content, its good tensile strength and flexibility, and ease of manipulation. Depending upon the particular application, the tape may be built up on paper, cambric or silk, or sandwiched between such carriers. It serves to insulate windings and bars of electrical apparatus. The dielectric losses here again depend upon the type and percentage of bond, which has to be selected to withstand satisfactorily the highest temperature that may occur under severe service conditions.

A combination of the oldest natural inorganic insulating material—mica—with one of the oldest synthetic inorganic substances—glass—produces Mycalex. Since 1932 the use of lead borate glass as the fusible vitreous binder has been abandoned in favour of leadless glass in order to overcome certain manufacturing difficulties and objections to the noxious fumes during the process of manufacture. This has resulted in a lower specific gravity of about 2·2, as against 3·4 for the original material. "L.D.S." Mycalex, as to-day's material is called, is easier to machine and the applications, at first limited to high-frequency work, have therefore been greatly extended and include many other insulating purposes. The Mycalex (Parent) Company in this country has recently installed plant to develop mouldings from this material with very fine limits which are difficult to obtain with steatitic and ceramic mouldings. A further advantage is the possibility of moulding metal inserts into the material as, for instance, in the case of brush-holder bars for high-temperature motors. Mycalex is resistant to arcing, and has a good electric strength and low power factor at various frequencies and temperatures. It is resilient and generally good mechanically. Arcing on the surface may fuse the material along the track without, however, causing it to become conductive. It can be used under humid conditions as its moisture absorption is very low.

Asbestos, the unique non-metallic mineral, is still used for insulating purposes in the form of asbestos paper, asbestos fabrics, hard asbestos boards, asbestos cements, asbestos moulded products and asbestos wire coverings. Its outstanding features are resistance to heat, chemical immunity, and absolute freedom from deterioration. Like other natural insulating materials for which no substitute has yet been found, its use is steadily increasing. More recent developments are flexible asbestos sheeting intended to serve as insulation for high-voltage conductors and coils where unusually high temperatures have to be withstood. Tapes and sleevings from superfine asbestos yarn are finding high-temperature applications. Low-voltage cables insulated with asbestos-varnished cloth and with an outer covering of tough asbestos braid are in extensive use in America.

Slate and marble are still used for switchboards, but are being substituted to a greater extent than in the past by impregnated cement-asbestos boards and synthetic-resin panels, which are more reliable electrically and mechanically and for which alternative sources of supply have been added in recent years.

VITRIFIED INSULATIONS

Porcelain still is, and for a long time is likely to remain, an indispensible material for the insulation of power transmission lines and for many other insulating problems, especially in connection with outdoor service. A synthetic substance has not yet been found which could effectively take the place of porcelain to stand up to all weather and atmospheric conditions. Synthetic materials, due to their greater toughness, accuracy in dimensions and machineability have, however, replaced porcelain for insulating parts not exposed to the weather or working under oil or compound. As regards the type of porcelain used to-day, improved results are obtained from the soft felspathic porcelain fired in an oxidizing atmosphere. On comparing the properties of the English soft porcelain with German hard porcelain, the latter appears to have a somewhat higher compressive strength, whereas in all other respects the English porcelain seems to be superior. About 10 years ago the tendency when making soft porcelain was to use an over-fluxed body, resulting in a very glossy material which, whilst giving the necessary vitrosity, was inclined to be mechanically weak. To-day, by exercising a rigid control of the particle size of the non-plastics quartz and felspar, particularly that of quartz, it has been found possible to obtain improved physical properties, including better consistency. Typical transverse-strength figures taken on a soft felspathic porcelain body composition some 10 years ago varied from a maximum of 10 800 to a minimum of 6 750 lb./sq. in., with an average of 9 360 lb./sq. in. over 10 tests. A more recent composition shows figures of a maximum of 12 800 to a minimum of 12 100, with an average of 12 600 lb./sq. in. These tests were carried out on unglazed porcelain produced by one of the leading English porcelain manufacturers. It has been recognized that a glaze added to the porcelain when stressed in tension will reduce the mechanical strength, while the glaze stressed in compression will, up to a certain maximum, increase the strength. In order to provide a key for cement it was usual to leave unglazed the surfaces of the porcelain in contact with the cement and to provide grooves or knurling. To-day this weakening of the cross-sectional area is avoided by the application of sand-glazing, which permits a continuous coat of glaze over the whole of the load-carrying surface. A further refinement in modern porcelain manufacture is the de-airing of the clay, thus eliminating cavities which adversely affect the mechanical and electrical performance.

Cap-and-pin insulators are to-day made by mechanical processes. For simple shapes hot pressing is now usual, and for more intricate shapes with thick sections the casting process is receiving greater attention. The introduction of humidity driers in which the larger sections are slowly warmed to 80–90° C. in an almost saturated atmosphere, the humidity of which is gradually lowered, has become necessary to avoid the strains and ruptures of the clay. The use of tunnel kilns and thermocouple-controlled schedules in intermediate ovens has given an impetus to the study of the effect of firing upon the physical properties of the insulators, and already valuable data have been collected. Low-voltage insulators are generally made by

pressing so-called "dust" in steel dies, followed by drying and firing.

If even better physical properties than those obtained with felspathic porcelain are essential, and expense is of secondary consideration, steatite (soapstone) is now available. As it was observed that the dielectric loss of the latter material is lower than that of porcelain, developments in this direction have led to the use of bonds for soapstone, which resulted in further reductions of loss factor, rendering the ceramic materials suitable for the radio industry as high-frequency dielectrics. By varying the ratio of the magnesia (MgO) to the silica (SiO_2) content in soapstone of general formula $3MgO$, $4SiO_2(H_2O)$, still better results were obtained, and this material forms the basis for coil formers, valve holders and similar low-loss applications. "Frequentite" is representative of this class. By adding titanium dioxide (rutile) the permittivity of the material is considerably increased, and by varying the ratio of TiO_2 to the other constituents a range of ceramics is obtained with permittivities of between 40 and 100. Thus an ideal dielectric has been created for low-loss trimmer condensers for short-wave circuits and similar purposes. For certain applications, however, the rather high temperature coefficient of this high-permittivity material was a disadvantage and it was found that with magnesium titanate ($2MgO\ TiO_2$) a material was obtained with a slightly positive temperature coefficient, the permittivity of this combination, however, being reduced to approximately 14. The development of these "low loss" ceramic materials on a commercial scale emanated from Germany, and Table 1 illustrates some properties of typical materials of this class which, incidentally, can be moulded to close limits. British manufacturers are now very active in this field and good products are already available which should meet the radio requirements equally as well as those previously imported. The raw materials for the steatite group and the rutile group of ceramics are obtainable within the British Empire.

For certain applications the principal requirement is to withstand sudden changes in temperature, a condition which is met by ceramics consisting of clay substances and steatite with a thermal coefficient of expansion of $1 \cdot 1 \times 10^{-6}$ mm. per deg. C. between 20° C. and 200° C. "Sipa" and "Ardostan" are German products of this type. Their permittivity is about 5 and their power factor at 1 Mc./s. is of the order of 0·003.

When silica (SiO_2) is fused with, for example, potash, soda, lime and lead oxide, glass, another vitreous material, is formed which, like porcelain, was discovered thousands of years ago. Glass has always been valued as a good electrical insulating material but until recently has only been applied in its rigid and rather fragile form which restricted its use on a broader basis. The latest experience on insulators of the line and suspension types, however, seems to indicate that glass insulators are seriously challenging the monopoly porcelain has enjoyed for so long in this field. Its main merits, apart from good electrical properties, are its resistance to high temperature and moisture and, in many instances, its transparency. Now that the production of alkali-free glass in the form of a fabric spun and woven from very fine thread has been established in this country, with the help of the originators in the U.S.A., a wider field of application has been opened up for it. As an inorganic textile material fibre-glass is more suitable than asbestos, due to its greater uniformity, its chemical purity and its excellent heat-conducting properties. Like all woven materials, glass-fibre insulation has to be varnish-treated for almost all its uses as an insulator. Owing to the great mechanical strength of glass fibre, the varnishing of the cloth can be carried out on the

Table 1

Material	Steatite group	Rutile group			
	Calit Frequenta	(Faradex) Condensa C	Condensa F	Condensa N	Tempa S
Specific gravity	2·7	3·9	3·9	3·7	3·1
Electric strength at 50 c./s., volts/mil	900–1 150	380	380–500	380–500	750
Power factor (tan d) at 20° C.:— 300 kc./s.	0·0003	0·00028	0·00033	0·00042	0·0007
50 Mc./s.	0·0005	0·00072	0·00043	0·00085	0·0008
Permittivity (κ)	5·5–6·5	80	65–90	40	14
Temperature coefficient of κ for 1 deg. C between 20° and 80° C., $\times 10^{-6}$	+ 140	− 700	− 700	− 360	+ 40
Insulation resistance at 300° C., ohms/cm³ $\times 10^{10}$	3·2	0·25	0·25	0·012	0·012
Compressive strength, lb./sq. in. ..	140 000	85 000–170 000	85 000–170 000	43 000–70 000	70 000–85 000

same plant as is used for treating cotton cloth, silk and similar material. So far no organic bonding medium has been found which will stand up to the very high temperatures which glass itself would permit in continuous service, but certain improvements have already been achieved in this connection, especially with combinations of inorganic with organic binders. While varnished cotton becomes brittle at high temperatures, resulting in a decrease in electric and mechanical strength, glass fibre is practically unaffected and retains its flexibility. The difference in resistivity of the two materials at high relative humidity is particularly marked, owing to the non-hygroscopic character of fibre glass. The tensile strength of this material is considerably higher than that of cotton or asbestos. Although the price for woven glass insulation is very high compared with that of other fabrics, its use seems to be justified by the savings it introduces in other directions. Motors, for instance, with fibre-glass-insulated windings can be run at much higher temperatures, which permits better utilization of the active materials and therefore a decrease in weight per horse-power output. Although the extent of such savings will have to be proved by experience over the next few years, it is at least certain that the use of glass insulation in place of the older materials constitutes a greater factor of safety which is so vital for mining, traction and other plant on which human lives depend. Glass-fibre thread is available as yarn spun from very thin "staple" fibre or from continuous filament. In this latter form it has first been used to insulate wires and other conductors, having several advantages over "staple" fibre, among these being a better space factor and greater tensile strength. The covering is finally treated with a binder to cement the layers together and act as protection against moisture. Continuous lengths of braided glass-fibre sleevings are already in use in America. Glass-fibre cords have been used with success as end-turn bindings and similar applications, owing to their very high tensile strength. Glass-fibre can further be used for the reinforcement of asbestos tape in place of cotton, resulting in better electrical properties without sacrificing the cushioning effect afforded by the asbestos base.

From synthetic-resin-bonded glass-fibre boards slot wedges can be rough-cut and, because of their great rigidity, forced into the slot and thereby trim themselves to the exact profile, thus rendering a lengthy machining operation unnecessary.

Turning to the organic insulating materials, I have first to refer to the now very important class of moulded composite insulations.

MOULDED COMPOSITE INSULATIONS

Under this heading falls the range of the commonly-called "Plastics." The last few years have seen phenomenal progress in the development of plastic materials of varied properties for almost all industries, although they were originally developed for electrical purposes.

We differentiate between plastics made from natural and those made from synthetic resins.

Of the natural resins used for bonding moulded compounds, the oldest and still the most important is shellac. Attempts to produce a real substitute have so far not been very successful, owing to the difficulty of attaining all the excellent properties which it possesses. One of the shortcomings of shellac in its rivalry with synthetic resins, however, has been its comparatively low softening point, unless heat-cured for a long time, but shellac chemists have in recent years succeeded in improving the thermal characteristics of the material by removing a small percentage of the soft fractions. Furthermore, by eliminating all the constituents of high acid number, the once much-feared "greening" of copper in contact with shellac has been successfully overcome. At the same time, the resistance of this so-called "hard lac" to water and petroleum hydrocarbons has also been improved so that the material has been reinstated in a number of applications which had temporarily been lost to synthetic materials.

No very special developments have taken place with the other natural resins used in the electrical industry.

Of the synthetic resins for the manufacture of plastics, the thermo-setting phenol-formaldehyde resins still predominate and the newer resins are only slowly entering their widespread field of many years' applications. These phenolic resin mouldings have been constantly improved both electrically and mechanically and their cost has become competitive with that of similar articles made from the older materials such as shellac, rubber, porcelain, etc. They are resistant to heat and impervious to water and their initial dielectric values are well maintained over long periods of hard service. Special grades with improved electrical properties for high-voltage work are on the market, as well as materials with specially good mechanical features for rough usage. Their main drawback is the tendency to track under discharge conditions, which explains why they have not yet entirely replaced the hard-rubber and cold-moulded inorganic compounds for applications where freedom from tracking is essential. In order to minimize this weakness of surface leakage, moulded materials are often coated with an alkyd resin solution such as glyptal varnish. B.S. No. 771 differentiates between five grades of mouldings of the phenolic type, starting with the two wood-filled types for general and improved general purposes, followed by the two fabric-filled types with medium and high shock-resisting properties. The fifth grade offers the highest heat resistance, the resin in this case being reinforced by inorganic fillers such as mica or asbestos. This grade has the further advantage of considerably lower moisture absorption, as is illustrated by curves in Fig. 1 for mouldings with the two kinds of fillers

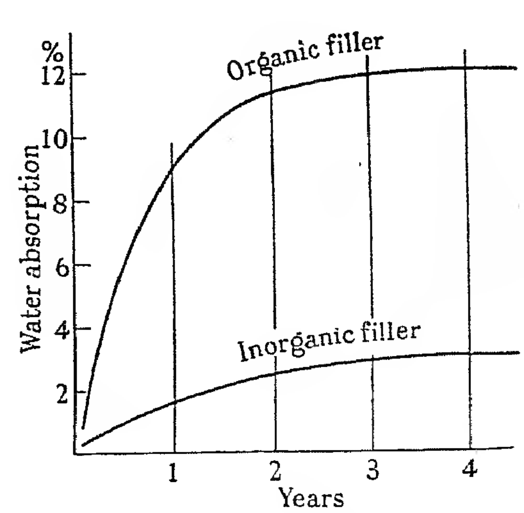

Fig. 1.—Water absorption of phenolic mouldings.

over a period of several years' immersion in water. B.S. No. 771 is an excellent guide to the designer for selecting the most suitable type of material for a particular purpose. For very special applications the large electrical manufacturing concerns, which partly produce their own moulding compounds, are often successful in their research laboratories in finding solutions to their particular problems and giving to the industry as a whole the benefit of their special work. Such, for example, is the case with a Fabrolite phenolic compound from which improved mineral-filled mouldings are secured which are anti-tracking and have greater mechanical and electrical strength as well as a satisfactory degree of arc-resistance, properties which are so essential in magneto assemblies. The chemists of the same laboratory also conceived the novel idea of impregnating and bonding acetylated cotton (Cotopa) with phenolic resin to a material which maintains high insulation resistance up to temperatures of 130° to 140° C. in the presence of engine oil. Further reference to the bakelite type of resin will be found under the heading of "Sheet, Rod and Tube Insulations."

Plastics made from cast phenolic resins have always played an important role in general utility trade, and their possible uses for electrical purposes have been considered from time to time. An old representative of phenolic cast resins is the American Catalin product which is now also made in this country. Plasticizing agents incorporated in this resin have made it less brittle than is the case with similar materials, and if slowly cured (over a period of days) its dielectric and mechanical properties can be further improved. Figures quoted for the special grade of "Electric Catalin" produced in America are repeated in Table 2 as a matter of interest. (The author doubts whether the electric strength at 90° C. is equal to that at 20° C. for this type of material.)

Table 2

"Electric Catalin"

Electric strength at 20° C. to 90° C., volts/mil	300–400
Permittivity between 20° C. and 80° C.	9–11·5
Power factor:—	
At 30° C.	0·017
At 60° C.	0·07
At 80° C.	0·20
Coefficient of linear expansion per deg. C.	$0{\cdot}75$–$1{\cdot}0 \times 10^{-4}$
Tensile strength, lb./sq. in. ..	9 000
Compression strength, lb./sq. in. ..	23 000
Modulus of elasticity, lb./sq. in. ..	380 000
Impact strength (Charpy), ft.lb./sq.in.	> 2
Water absorption	Negligible

The newer type of thermo-setting resin, i.e. urea-formaldehyde condensation resin, although to a high degree non-tracking, has only in a very few cases been able to replace the phenol-formaldehyde resins in the electric field. Switch bases, in which freedom from tracking under all conditions is essential, are moulded from this type of resin instead of porcelain or bakelite. Urea mouldings, being considerably more moisture-absorbent than phenolic resins, are precluded from applications under damp conditions. Adding to this limitation that of dimensional instability, it is understandable that the electrical design engineer has so far restricted the use of this plastic to the domestic field where conditions of service are generally favourable. Here it possesses the advantage over the phenolics of being obtainable in any desired colour. It is very suitable for injection moulding, which offers the advantage of cheapness on a mass-production scale.

More stable materials which are less moisture-absorbent and mechanically and electrically better than urea resins are the melamine-formaldehyde moulding powders of Swiss origin. Melamine being a chemical of the amino group, resins made from it are otherwise similar to those of the urea resins and will, it is expected, receive further attention in this country after the war. Where anti-tracking properties coupled with good electric strength are of first consideration, aniline-formaldehyde resins have come into prominence. Plant on a large scale for the manufacture of this material was first installed in this country, and the experience gained therefrom has been the basis for the production of similar material in other countries. Owing to the higher mechanical strength of analine-formaldehyde resin compared with that of the phenolic resin, strong mouldings can be obtained from it without the incorporation of fillers. They have the advantage of extremely low water absorption. Aniline-formaldehyde resins are of the thermo-plastic variety but their plastic yield is higher than is common for thermo-plastics so that they can be used up to temperatures approaching 100° C. without deformation. In Table 3 some of their properties are indicated.

Table 3

Aniline Pure Resin ("Panilax")

Tensile strength, lb./sq. in.	8 000–10 000
Cross-breaking strength, lb./sq. in. ..	13 000–17 000
Shear strength, lb./sq. in.	11 000–12 000
Impact strength, ft.-lb./sq. in. .. (Izod pendulum test, ½ in. sq. unnotched specimen)	6–9
Plastic yield (Martens)	> 100° C.
Modulus of elasticity, lb./sq. in. ..	$0{\cdot}5$–$0{\cdot}6 \times 10^6$
Specific gravity	1·22
Surface resistivity, Ω/cm²	$> 3 \times 10^{14}$
Volume resistivity, Ω/cm³	$> 2 \times 10^{15}$
Power factor:—	
50 c./s.:—	
At 20° C.	0·005–0·02
At 90° C.	0·02 –0·05
1–50 Mc./s.:—	
At 20° C.	0·004–0·01
At 90° C.	0·01 –0·02

By a special process aniline resin can be incorporated into paper pulp by chemical precipitation within and around the beaten fibre which, after neutralizing, is made

into paper on a Fourdrinier paper-making machine. Further reference to this material will follow under the heading of "Sheet, Rod and Tube Insulations."

During the past 10 years fruitful developments have taken place in the chemistry of plastics in general by which the electrical industry has naturally benefited. New substances have been created without which the commercializing of the electrical innovations of recent times, particularly in the field of high frequency, would have been greatly hampered. Most of these new materials known as "polymers" and "co-polymers" and produced as solids, plastic compounds, liquids, and even gases, originated on the Continent and in America, but the present period of war has already proved that science and industry in this country are well equipped to offer similar materials, in some cases with even better properties. The scope of their application is rapidly widening and the chemical industry is now taking a keen interest in their further development.

In reviewing the plastic substances of the non-hardening type which have become useful to the electrical engineer during later years, those built up from cellulose may be mentioned first. Their electrical properties are only moderate but their mechanical features are outstanding, especially the resistance to shock. Water absorption and ageing are fair but the plastic yield is low—in fact they suffer from excessive cold flow which further limits their possibilities as electrical insulating materials to applications where stability is not essential. These resins can be moulded by the three main methods, namely compression, injection and extrusion. Glass-clear and all colours are obtainable. Mixed ester cellulose compounds such as cellulose acetate butyrate, benzyl cellulose and ethyl cellulose, are more recent developments in an endeavour to improve moisture resistance and electrical properties. Ethyl cellulose, the ether of cellulose and ethyl alcohol, is particularly tough, flexible and extensible, and therefore very suitable as wire coating and as cable sheathing. It is alkali-proof and acid-resistant. In film form ethyl cellulose has an electric strength of up to 1 500 volts per mil and a permittivity of 2·6 at 60 c./s. and 20° C.; 2·9 at the same frequency but at 100° C.; at 1 000 c./s. the permittivity is 3·9 with a power factor of 0·00025. A very recent outlet for this material has been found as the dielectric in electrolytic condensers.

Polystyrene

The basic chemical for this material is styrene ($C_6H_5.CH = CH_2$) which polymerizes to solid products of high molecular weight (long-chain polymer) which are soluble in aromatic hydrocarbons and some other solvents. Those of the highest molecular weight (claimed to be as much as 100 000) have the best mechanical and electrical properties, low water absorption and very good resistance to chemical reagents. The thermo-plastic characteristic of the material renders it particularly suitable for production by injection moulding, and the introduction of this process has resulted in a marked speeding up in the development of the material. "Trolitul" is the name of the material of this type which was first made in Germany. One of the English products of repute is "Distrene" Styrol which is glass-clear in appearance, and by the addition of plasticizers has been rendered free from internal stresses from which the initial materials suffered. As can be seen from Table 4, it has a very low power factor and is therefore destined for extra-high-frequency service. For example, long fibres can be spun into threads which are used for high-frequency cable insulation. Coaxial cables for communication purposes and television are extruded from this compound. Polystyrene in film form is an excellent dielectric for the manufacture of capacitors for radio apparatus and other purposes.

Table 4

"DISTRINE" STYROL

Electric strength (volts/mil) at 20° C.:	
Sample $\frac{1}{8}$ in. thick	500
Sample 10 mils thick	1 200
Surface resistivity, MΩ/cm^2 ..	10^{10}
Volume resistivity, MΩ/cm^3 ..	10^{11}
Permittivity and power factor:—	κ tan d
At 50 c./s.	2·2; 0·0002
At 1 kc./s.	2·2; 0·0003
At 20 kc./s.	2·1; 0·0004
At 540 kc./s.	2·1; 0·0002
At 1 Mc./s.	2·3; 0·0002
At 40 Mc./s.	2·3; 0·0001
Specific gravity	1·05
Water absorption in 48 hours ..	Nil
Tensile strength, lb./sq. in.	6 000–7 000
Cross-breaking strength, lb./sq. in. ..	12 000–15 000
Compression strength, lb./sq. in. ..	17 000
Impact strength (Izod notched bar; 25° C.), ft.-lb./sq. in.	0·25–0·3
Modulus of elasticity, lb./sq. in. ..	5×10^5
Softening point (Martens)	87° C.
Thermal conductivity, 10^{-4} cal./sec./cm^2/deg. C./cm.	1·9
Coefficient of linear expansion per deg. C.	0·0001

Another new class of plastic of interest to the electrical engineer is that of the acrylic resins, which have better ageing properties and lower water absorption than the cellulose derivatives. Acrylic resins are expensive at present and it is hoped that the more economic production facilities which are required to satisfy the heavy demand for this material in the aircraft industry will favourably affect the price and thereby prepare for its more extended use in the electrical field, if not immediately, then certainly after the war. British products of this class are "Diakon" and "Perspex," which are polymers of methyl-methacrylate, their characteristics being listed in Table 5.

Plastics of a non-inflammable nature are to be found among the vinyl resins. Developments in connection with this resin during the last few years comprise the compounds made from acetylene and converted into vinyl chloride and vinyl acetate by polymerization and co-polymerization. They possess excellent electrical properties and are highly resistant to chemical action. They are very tough and have low water absorption and are commanding attention

Table 5

"PERSPEX"

Permittivity:—	
At 50 c./s.	3·0
At 10^6 c./s.	2·8
Power factor (tan *d*) at 10^6 c./s. ..	0·02
Surface resistivity, MΩ/cm²	$> 10^8$
Volume resistivity, MΩ/cm³	$> 10^9$
Puncture voltage, $\frac{1}{8}$ in. thick specimen (after 24 hr. in an atmosphere of 75 % humidity, and also after 24-hr. immersion in water), volts/mil ..	380
Specific gravity	1·2
Water absorption, 7 days at 20° C. on sample 2 in. × 2 in. × $\frac{3}{16}$ in. thick, percentage by weight	0·4
Tensile strength (cold), lb./sq. in. ..	7 000–8 000
Impact strength (cold), ft.-lb./sq. in. ..	3–4
Shear strength (cold), lb./sq. in. ..	9 500–10 000
Modulus of elasticity (cold), lb./sq. in.	450 000
Softening point (Martens)	55° C.–60° C.

in their applications as extruded sleevings and as cable sheathing. Some of the proprietary names of this type of resin are "Mipolam," "Luvican," "Koroseal," "Bexane" and "Astralon." The characteristics shown in Table 6 give an idea of the main properties of vinyl plastics.

Table 6

VINYL PLASTICS

Volume resistivity, MΩ/cm. ..	3×10^6
Permittivity	3 to 4·2
Electric strength, volts/mil ..	400 to 800
Specific gravity	1·2 to 1·35
Tensile strength, lb./sq. in. ..	8 000
Compression strength, lb./sq. in.	27 000
Impact strength (notched bar), ft.-lb./sq. in.	5·6
Modulus of elasticity, lb./sq. in.	About 500 000
Softening point	70° C.–100° C.
Inflammability	Burns with difficulty

Data are lacking on the other electrical characteristics, which are supposed to be very similar to those of the acrylics.

Polymers of the above types are suitable for the production of films and foils as used in a diversity of insulating problems. An example is "Vinifol," an electrical insulating foil obtainable in very thin strips of reasonable length to be applied in a similar manner to tape.

Polyethylene, made apparently only in Great Britain, is a polymer of the gas ethylene. The electrical properties of this class of material are claimed to be even better than those of polyvinyl plastics and it is particularly suitable for forming by the extrusion process. In ribbon form it is used for insulating conductors which do not reach too high a temperature in service. The material is also obtainable in sheets.

Having mentioned recent developments in synthetic resins of the different types, it will be noticed that so far little information is available as to the possibility of incorporating fibrous or other fillers as in the case of phenolic resins. Investigations in this direction are in progress and results are awaited with interest.

The last moulding compounds to be referred to, but among the first in existence, are those with rubber binders. They are excellent insulators and were it not for the tendency of natural rubber to age prematurely the search for synthetic substitutes would not have been so intensive in late years. Ebonite and similar vulcanized-rubber compounds have so far, however, maintained their position as insulating materials for scientific instruments and for telephone and radio applications where temperatures do not exceed 70° C. Loading the compounds with fillers, and a more critical selection of the sulphur content, resulted in a general improvement of their properties other than electrical, which were always outstandingly good. Like natural rubber, the synthetic compounds are highly polymerized hydrocarbons. Poly-iso-butylene is one of the basic compounds of synthetic rubber. It is claimed to resist boiling water without detriment to its electrical characteristics. Its power factor at 800 c./s. is about 0·0004 at 20° C., increasing only by 1 % at 85° C. The electric strength and resistivity are very satisfactory. The German synthetic rubbers of the "Buna" type are polymers of butadiene or their co-polymers with styrene or acrylic nitride. They can be vulcanized with sulphur and are more resistant to grease and oils. "Neoprene" is already well known and is produced by the interaction of chlorine and butadiene. Owing to its general superiority over natural rubber it is being used in many directions in place of the latter and, as it is considerably less inflammable, it is finding a special outlet as the insulation of fire-resisting wires and cables.

Moulding compounds in general require expensive tools for shaping, especially where large articles are concerned. This, of course, also applies to phenolic mouldings and is the reason why materials which can be machined from solid blocks are still extensively used as constructional insulation members in electrical plants. In this connection, wood free from moisture and well seasoned has always been a useful material to the electrical engineer. Because of its excellent mechanical properties and its ease of machining, its applications are manifold. In order to prevent re-absorption of moisture, the wood must be impregnated either with oils or, still better, with appropriate synthetic resins. By a vacuum process the liquid resinous compound enters the interstices of the cellular structure and by heat treatment the resin is polymerized, cementing the structure into an inert body of improved mechanical and electrical properties. Greater homogeneity of the material is attained by impregnating thin layers (veneers) of wood and bonding them together in hydraulic presses, the platens of which can be heated and cooled. Experience in recent years has indicated that the thinner the individual laminations are the higher will be the mechanical strength of the bonded plywood, but the cost of production also increases. New attempts to densify solid impregnated timber have recently produced a homogeneous material

known as "Tensovic," which is claimed to be free from cracks and to have a tensile strength of over 30 000 lb./sq. in. coupled with good electrical properties. Commercially obtainable impregnated wood has a tensile strength of 18 000–20 000 lb./sq. in., with a modulus of elasticity of 2–3 $\times 10^6$ lb./sq. in. The compressive strength is quoted as 18 000–30 000 lb./sq. in., depending upon the type of wood, which also explains the variation of shear strength from 2 000 to 7 000 lb./sq. in. The French product "Permali," which is representative of this class of material and is now made in England, has an average water absorption of 3 % after immersion for 24 hours. The electrical properties of synthetic resin-impregnated wood depend, of course, on the electrical characteristics of the impregnant in the first instance, and on the degree of uniformity of the impregnated wood, which is largely governed by the thickness of the veneers. So far, alcohol solutions of phenolic resins are used for impregnation under vacuum and pressure, but recently investigations have been started into the impregnation with aqueous solutions by simple immersion.

Wood in thicknesses of a few thousandths of an inch is very fragile and could hardly be handled satisfactorily for further processing. By man's ingenuity, chemical and mechanical treatments have been applied to wood to disintegrate the structure into a fibrous mass which on elaborate machines is again assembled to a continuous web, now called paper. Improvements in paper making are of necessity slow as the machinery for its production is very intricate and costly and does not easily lend itself to experimenting. A little headway has, however, been made during the last 10 years in obtaining greater uniformity in the mechanical and physical characteristics of paper. This applies particularly to that made from chemical wood pulp stock known as "kraft" which, for the manufacture of synthetic-varnish-treated laminated materials, is gradually replacing the more expensive rag papers made from linen, cotton flax, etc. Efforts are being made to produce papers with more even strength in both directions, a condition which is desirable for the pressing of laminated boards with mechanical properties as near as possible equal in all directions. Paper as an insulating material suffers from its ready absorption of moisture, especially where it is used as such without further treatment. Research has been carried out over the last few years in order to decrease the affinity of paper to moisture without affecting the good electrical and mechanical properties of the fibrous substance. The most promising line of attack has been that of esterification of the fibre, in particular by acetylation similar to the treating of yarn known as cotopa yarn. Such improved paper already plays an important part in the insulation of cables, especially in the making of cable joints.

In an endeavour to obtain a more homogeneous impregnation of the paper, the phenolic so-called "pre-mix" processes have been evolved in England as well as in other countries. In the original process the resin in powder form was mixed with the paper pulp in the beater and the paper or board made therefrom. In an improved method the fibre is present during the making of the resin in the digester, resulting in a more intimate impregnation. Multi-ply presspapers and pressboards built up from "pre-mix" stock and compressed between the heated platens of a hydraulic press have characteristics somewhat similar to those of vulcanized fibre and for many applications form a useful substitute for the latter.

In America vulcanized fibre has been rendered more water-resistant by impregnating wet cleaned fibre with an acid solution of an aniline-formaldehyde resin, precipitating the resin by neutralizing with dilute alkali, washing out the excess alkali and drying and pressing as with regular fibre. This special fibre of low moisture absorption and improved electrical properties has found applications in humid atmospheres where ordinary fibre was unsuitable.

SHEET, ROD AND TUBE INSULATIONS

In the field of high-voltage design, boards of better and more reliable properties are available in the class of dielectrics known as synthetic-resin bonded-paper boards. The last 10 years have seen considerable advancement in quality and selection of such board. The engineer producing this type of insulation has to be conversant with the insulation problems of all branches of the electrical industry and has to keep in constant touch with the designer of electrical plant. As the properties of laminated materials depend to a high degree on the preparation of the raw materials from which they are made, a good knowledge of their manufacturing processes is essential. The realization of these conditions, resulting in close co-operation between the insulation manufacturer and the producer of paper, fabric and the resins used for their bonding, has been responsible for the high standard reached in this industry, especially so in this country. As can be seen by comparing figures for mechanical strength, laminated dielectrics are very much stronger than straight resin-moulded materials and for this reason still maintain their prominent position in the manufacture of high-voltage power plant. Special attention has been given to the improvement of the moisture-absorption characteristics, with marked success in at least one instance where a maximum water absorption figure of 0·07 % after 24 hours' immersion has been achieved. This gain, however, has only been possible at the expense of some reduction in mechanical strength at high temperatures, and research for further improvement is under way.

A development of special interest, and mentioned earlier in this review, is the paper-base insulation in which aniline-formaldehyde resin and fibre pulp are chemically united as against the impregnation or coating of paper. The electric strength of board pressed from this special paper is high, particularly in the direction of the paper layers, and the greater freedom from tracking compared with phenol-formaldehyde resin bonded insulation is noteworthy. Its main characteristics are shown in Table 7.

Improvements have recently been made in the electrical characteristics of synthetic-resin bonded-fabric board, once mainly used as mechanical supports and as panels for moderate insulation requirements. This has largely been brought about by the demand, in connection with transformer and switchgear construction, for example, for material having a higher impact strength than paper-base insulation. A comparison of electric strength with that of paper-base boards is indicated in Fig. 2. As can be seen, the values are less than half those for paper board, but it should be pointed out that they are conservative and can be guaranteed as the minimum if required.

Table 7

"PANILAX" FIBROUS BOARD OF 47 % RESIN CONTENT

Specific gravity	1·35
Water absorption (per cent) in $\frac{1}{4}$-in. thickness:—	
24 hours	0·4
7 days	2·0
Tensile strength, lb./sq. in.	15 000 (min.)
Shearing strength, lb./sq. in.	12 000 (min.)
Cross-breaking strength, lb./sq. in. ..	25 000 (min.)
Compression strength, lb./sq. in. ..	35 000 (min.)
Minute breakdown value through laminae in oil at 90° C., $\frac{1}{4}$-in. thick specimen, volts/mil	400
Minute breakdown value along laminae in oil at 90° C., volts/in.	> 70 000
Permittivity	4–5
Power factor, $\frac{1}{4}$-in. thick, at 20° C. ..	0·02–0·06

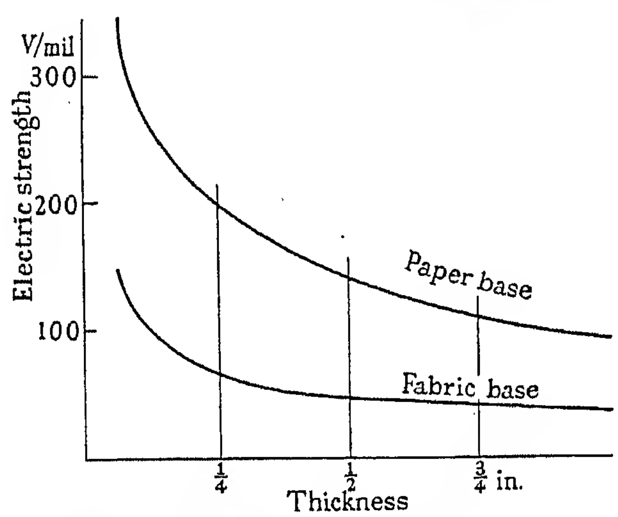

Fig. 2.—Electric strength of synthetic-resin bonded-boards. Test conditions as in BS. No. 316.

Tubes and cylinders of synthetic-resin bonded-paper are available having the necessary mechanical strength and impermeability to be suitable for containers of air or gas under pressures of the order of 200 lb./sq. in. The same grade of material is also used for the manufacture of insulating tanks to hold oil-immersed apparatus, and for testing purposes. The volume of oil required for a given test voltage is very considerably less than when a metal tank is used, and less heating energy has to be supplied to maintain the oil at any given temperature. The practice is growing of using absorbent cylinders for the support of transformer windings, and as barriers between the high- and low-voltage windings. Such cylinders absorb transformer oil and have a permittivity of the order of 3·5. Since the permittivity of a synthetic-resin-bonded paper cylinder of the usual type is about 5, while that of oil is about 2·5, the absorbent cylinder allows a more balanced design. A presspaper of high quality such as "Elephantide" is used when winding these cylinders, the layers being bonded together with a heat- and oil-resisting natural gum and, providing the necessary precautions are taken to dry out the cylinder thoroughly before its immersion in oil, a high electric strength is obtained.

Bushings and Insulators

The manufacture of synthetic-resin varnished-paper bushings, in particular those of the condenser type, has been firmly established in this country in little more than this past decade, and has thereby made the electrical industry independent of imports of this special class of insulators. The requirements of the Grid electrification scheme were the main incentives for this rapid development. Year by year improvements have raised the standard of these articles, but at the same time the severity of service has increased. Apart from flashover performance, the checking of power-factor behaviour under different conditions has been found to be the most useful criterion for assessing the quality and probable life of such insulators. More recently, greater importance has also been attached to freedom from any audible internal discharges—known as "hissing"—under service conditions. This stipulation imposes an undue percentage of rejection upon the manufacturer when applied to designs of insulators particularly prone to hissing due to unfavourable electrical stressing. In spite of the hindrances attendant upon war-time, there is every indication that the difficulty will be overcome in pursuing the efforts of more rigid control over raw materials and details in the manufacturing processes. The improvements mentioned under "Synthetic resins" are, of course, contributing towards this end.

Attempts have been made to mould insulators from pure resin in order to obtain a more homogeneous material not affected by atmospheric conditions. Small insulators of the bulk type have been produced in this way, but for insulators of the condenser type only a small measure of success has yet been achieved. Meanwhile, no efforts are spared to render the synthetic-resin varnished-paper insulators more moisture-proof by covering the entire surface with superimposed films of hard, endurable, insulating varnish. The resultant synthetic glaze has very good resistance to the ingress of moisture but is not sufficiently immune from the effect of surface leakage to be used under tropical conditions where water from condensation may actually cover the insulator.

VARNISHES

On reviewing progress in the development of insulating varnishes in general, the merit of fundamental advancement during recent years is claimed by those of the synthetic type. The long-established oil varnishes still find extensive use for finishing and impregnating, and combinations of the natural and the synthetic raw materials often present the best solution for a particular problem. Straight phenolic varnishes, rendered more flexible by the addition of a small quantity of plasticizer, have long been appreciated for their good ageing and protective qualities. Varnishes of the urea-formaldehyde group have the advantage of greater resistance to tracking and are unaffected by alkalis as well as acids, but they do not stand up to the influence of moisture so well as the phenolic varnishes. Glyptal varnishes unite all the desirable features mentioned above and maintain the original properties at elevated temperatures without carbonization taking place. They require, however, long periods at high temperatures to polymerize to a satisfactory state of cure. Alkyd varnishes

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made from glycerin and phthalic acid or maleic acid are particularly tenacious to metal and are soluble in the usual solvents. Many applications have been gained by the modified phenolic resin varnishes which will mix with linseed oil and tung oil (China wood oil) and are soluble in benzine or benzol. Another variety of phenolic resin enters into chemical reaction with the drying oils, thereby offering the advantage of hardening throughout the film, a characteristic which is essential for the correct impregnation of the windings of armatures and rotors for high speed, if varnish throwing is to be avoided. They are improved substitutes for natural resin varnishes and oil varnishes. Special varnishes from aniline resin are distinguished by their very low moisture absorption and their excellent dielectric properties, which include freedom from tracking. In cases where stress is laid on non-inflammability of varnishes, this condition is partially met by those based on chlorinated rubber. Cellulose derivatives are also suitable for varnishes, benzyl cellulose varnish in particular exhibiting water-repelling and good electrical properties.

A development of special interest in this country was that of the catalytic oxidation of rubber yielding a viscous gum called "Rubbone." By mixing this with drying oil a finishing varnish is obtained which, on heating in air, oxidizes to a flexible, tough film with good electrical properties. It is believed to be particularly suitable as an enamel for copper wires.

INSULATING OILS

In recent years greater importance has been attached to the avoidance of fire risk in electrical installations, and therefore a start has been made to substitute non-inflammable liquids for insulating oils for immersed transformers, switches, condensers and other apparatus. These are chlorinated hydrocarbon liquids such as, for example, "Pyranol," which is composed of mixtures of hexachlor diphenyl and trichlorbenzine. The permittivity (κ) of "Pyranol" is about 5 and its use, therefore, in static condensers for power-factor correction has the advantage of doubling the capacitance for equal dimensions as against the ordinary mineral oil of $\kappa = 2 \cdot 3$. The viscosity can be varied from water like white oils to a viscous yellowish fluid. Since linseed-oil varnishes are attacked and dissolved by this class of fluid, the impregnation of windings should preferably be carried out with one of the synthetic class of varnishes.

TREATED SHEET INSULATIONS AND SLEEVINGS

Varnished cloth and tape of the drying oil type has been improved year by year and is predominantly in use to-day in a quality which has great uniformity in physical and electrical properties. New applications have called for the development of many special grades. Flexibility and tensile strength have gradually been improved and the material is to-day produced in continuous lengths without joins up to about 400 yards. Sewn bias tape is rapidly disappearing.

Experience in cable practice has shown that the bitumen-loaded black varnish tape has better ageing properties and is therefore gaining preference over straight oil cloth. Where exposure to the atmosphere is likely to occur, the black cloth is able to maintain its initial qualities in the face of unfavourable conditions, apart from having improved moisture-resisting properties and better electric strength.

Special materials as, for example, tapes tacky on one side have been produced, and there is now a large demand for an oiled cotton cloth tape tacky on one side which finds wide application in wire covering under the braiding or for protection against oil and petrol for aircraft and automobile work.

In common with all other activities in the field of electrical insulation in this country, investigations are in progress to establish whether the synthetic varnishes would offer advantages over the present treatments. To quote an instance, they have, however, so far failed to support the American tendency to substitute a phenolic varnish for the oil-base varnish in the case of Empire cloth.

Insulating sleevings of the original type of impregnated and varnished textile bases are still in great demand in the electrical industry, but the extruded sleeving referred to under "Moulded Composite Insulations" has already gained a firm footing. The compounds used for the latter are thermo-plastics such as polyvinyl-acetates and polyvinyl-chlorides. These have rather poor heat resistance, softening at about 70° C., but excellent electrical and mechanical properties, and moreover are not attacked by acids, alkalis, oils, etc. They can be extruded from a nozzle or die, direct on to the wire. If condensation products of polymerized vinyl derivatives with aldehydes are used, the safe working temperature is raised to over 150° C. but at the expense of the resistance to chemicals. Some extruded sleevings are characterized by their low dielectric loss, non-inflammability, and great flexibility over a wide range of temperatures (from 20° C. to 100° C.).

Typical British materials are "Tenaplas," "Micoflex," and "Periflex," which are made from I.C.I. vinyl-chloride known as "Welvic" and are obtainable in all colours. The electric strength of this kind of material is of the order of 30 to 40 kV/mm., and they are therefore suitable for high-voltage circuits. As their dielectric losses are very small, they are used for low-capacitance cables for high-frequency applications.

"Formvar," a resinous product obtained by reacting formaldehyde and hydrolized polymerized vinyl ester, is favourably looked upon in America as an enamel for wire. "Formex," a polyvinyl-acetate type resin, serves similar purposes and compares favourably with the older enamels. It is tougher and has better resistance to abrasion. "Formex"-enamelled wire is particularly suitable for windings of small motors. It would appear that all the desirable features for wire enamels are incorporated in these new materials, and yet the latest reports from across the Atlantic already praise the even newer substance, "Nylon," as a further advancement in toughness without impairing the electrical qualities.

In concluding this review of progress on dielectrics, it may be stated that during the last 10 years, apart from improving existing materials, a solid scientific basis has been established for the theoretical and technical exploitation of the new substances. This should help the electrical industry to solve the new problems which will arise when the present struggle for freedom of action, in which our engineering activities are involved, has been brought to a satisfactory conclusion.

ELECTRICAL APPARATUS FOR TESTING REACTION-TIME AND HAND-AND-EYE CO-ORDINATION*

By R. C. WOODS, Associate Member,† and A. S. MacDONALD.†

(*Paper first received 1st March, and in revised form 16th July, 1940.*)

SUMMARY

The adoption of machine accounting in an engineering works necessitated the addition, to the existing battery of psychological tests for the selection of staff, of reaction-time and hand-and-eye co-ordination tests.

Two new instruments, consisting almost wholly of standard telephone components, are described, their operation sequences are given and reference is made to the accuracy of the reaction tester.

The results of the practical tests with these instruments are shown and simply discussed.

The instruments, simple to operate and both accurate and reliable, were adequate for their purpose, and it is suggested that they may have a wider application.

INTRODUCTION

During 1939 it was decided to adopt machine accounting in a large works employed mainly on light electrical and telephone engineering work involving an immense number of components and many processes and thus requiring quick and accurate cost control. It was appreciated that the staff to operate this system must possess qualities differing from those of the existing accounting staff and that the training would necessarily be intense, as contrasted with the gradual instruction obtained by entry as office boy and advancing to more responsible work. The selection of the necessary staff was in consequence among the major considerations involved in planning the new organization.

The machines were to be operated by girls and the normal learning period was known to be about 3 months. It was thus highly desirable that operators should be chosen with care, as the failure of any to reach the required standard of efficiency would be a complete loss, would retard the smooth introduction of the new system and also be most unsatisfactory to the individual. The authors were therefore called upon to assist in the selection of staff and a survey was made of the qualities considered both desirable and essential, so that the appropriate tests could be chosen. Most of the test requirements could be met from the existing battery of tests for intelligence, perseverance, manual dexterity, etc. Since it is a large part of an accounting-machine operator's duty to translate written information into the depression of the appropriate keys of a keyboard, in which operation she should eventually reach high and consistent accuracy combined with a good speed, it was very desirable to choose as trainees girls with at least a reasonable inherent ability in this direction. Hence two new tests were required, one to determine the reaction time absorbed in observing a visual signal and converting it into a manual movement, the other to measure the co-ordination of manual responses and visual stimuli.

The functions required from each testing device were determined and the means of providing them were considered. The temptation to add facilities for side issues of possible interest was recognized and it was agreed to concentrate on simplicity in design and operation. Of the two testers, that for reaction time presented more difficulty, as the co-ordination tester appeared to be a fairly normal problem in telephone switching. Tentative consideration had previously been given to the former, and as the proposals involved time control of a rotary switch, they were put to the Circuit Laboratory of the works for consideration and advice. From the new source of ideas so tapped came the suggestion that the desired result could be more readily and accurately attained by using as the timing device a spring-driven constant-speed rotary mechanism, electrically controlled and carrying an indicating pointer. The possibilities of error would thus be reduced, and the known accuracy and reliability of the simpler device were points in its favour. An experimental unit was made, and after minor modifications had been incorporated was found to be satisfactory.

The functions, operation and design of the two instruments will now be described.

REACTION-TIME TEST

Practical Details

It was desired to measure the time taken in observing a particular visual signal and in converting it into a suitable manual operation. An element of distraction, in the form of another visual signal, was to be introduced to test the degree of the candidate's concentration. From this condition the following requirements for the actual apparatus were determined.

Two small lamps (one red, one white) and a light press-key should be placed before the candidate. The lamps should each be lit 10 times in a cycle of the device, in a predetermined irregular sequence at irregular time-intervals. There is no special significance in the choice of colours, a good contrast being all that is desired, and this is limited by the lamp-cap colours available. The device should be capable of measuring the reaction time to either red or white lamp at will. The candidate shall be required to extinguish the chosen light as rapidly as possible by momentarily depressing the key immediately the lamp lights, and to ignore the flashes from the other lamp.

The instrument should record the total number of lamp flashes, measure and indicate the sum of the reaction

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times for the 10 effective signals and also record the number of errors (if any), i.e. the number of key operations made on the signal which should be ignored.

The general appearance of the instrument is as shown in Fig. 1. It will be seen that the control and measuring equipment is a separate unit which may be placed remote from the lamps and press-key, so that the sound of the relay and switch operations will not either assist or disturb the candidate. The control unit comprises the timing mechanism and its electromagnet control, uniselector switch, 5 relays, 2 meters, 3 lever keys giving 5 switch functions, an electrolytic condenser and the necessary resistance coils, wiring, etc. The sum of the 10 reaction times is registered by a pointer travelling over a circular scale.

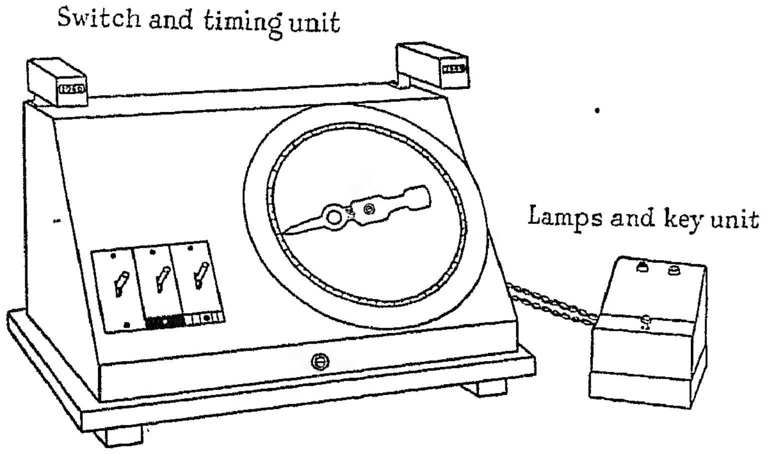

Fig. 1.—Reaction-time tester.

The timing mechanism is a miniature clockwork motor, governor-controlled, normally held by a spring-loaded brake which is released by electromagnet. The motor is of the well-known automatic-telephone dial type but with special driving spring and modified to give 2 revolutions of the pointer, so as to cover the maximum time involved. A finger-hole is provided in the pointer for rewinding the spring. The pointer is driven at a speed of 110° per second, which gives a convenient open time-scale. It is released each time the effective lamp is lit and is stopped immediately the "stop" key is depressed. Thus at the end of 10 effective signals the pointer indicates the sum of 10 successive reaction-times.

The sequence of operation for a test can be followed from the circuit diagram (Fig. 2).

The homing key H is thrown, whereupon the switch is energized and steps to its zero position, where it stops. The switch is then in a position to give the full test sequence. H is then restored. Assuming response is to be tested on the A lamp, the A key is thrown. If timing were being tested on the B lamp, the B key would be used instead.

All is now ready for the test to commence; the candidate has been instructed in the test and is seated, with finger on press key "stop" and facing the two lamps.

The examiner throws the start key ST.

Relay A operates, and electrolytic condenser QA is charged. Contacts A1.2 close the circuit for relay T.

Relay T operates.

T1.2 disconnects switch driving magnet SDM of switch S, so that it remains de-energized.

T3.4 completes circuit of lamp A, which is thus lit.

T5.6 prepares circuit for relay R.

T7.8 completes circuit of "totals" meter TT.

T9.10 completes circuit of timing mechanism TM or prepares circuit for "incorrect" meter M, according to the condition obtaining.

T11.12 completes circuit of relay TA.

Relay TA operates.

TA1.2 and TA3.4 disconnect energizing circuits of relay A and condenser QA respectively.

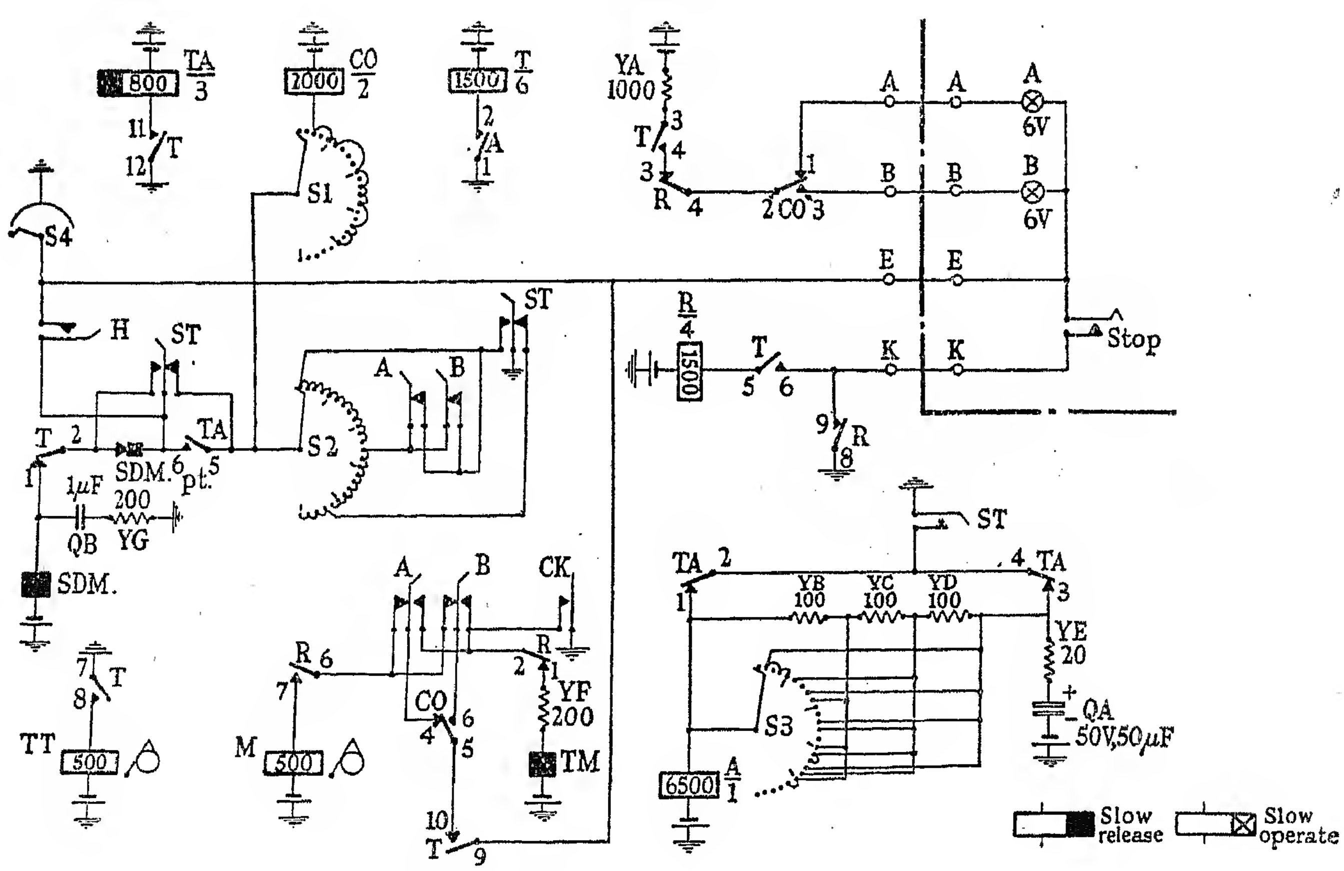

Fig. 2.—Reaction-time tester circuit.

TA5.6 prepares a circuit for SDM.

The timing mechanism will now drive until arrested by the operation of relay R, which operates when the candidate depresses the " stop." key in response to the glow of the lamp A.

Relay R operates.

R1.2 disconnects the timing-mechanism electromagnet TM, and the pointer movement is arrested.

R3.4 disconnects lamp A.

R6.7 completes the circuit of the "incorrect" meter if the " stop " key is wrongly depressed when the lamp to be ignored is lit.

R8.9 locks relay R until relay T releases.

With the energizing circuit interrupted at TA1.2 and TA3.4, relay A releases as soon as the current in the closed circuit of condenser QA and relay A has fallen to the release value of the relay. Relay A releasing, releases relay T which disconnects all test circuits and relay TA. The release of relay T also completes a circuit for switch-driving magnet SDM during the slow-release-time of relay TA.

Relay TA releases to allow the switch S to step, and also reconnects relay A.

A uniselector switch steps to its next contact position each time the driving magnet is de-energized.

The above cycle of operations is then repeated until 10 tests have been made.

The uniselector switch functions are as follows:

*S*1 *arc* is used to change-over from lamp A to lamp B by the operation of relay CO on certain predetermined contacts. The timing circuit is also changed at the same time, so that the timing and "incorrect" metering operations correspond with the chosen order of test.

*S*2 *arc* determines when 10 tests have been made. If one key only is thrown (the normal condition) the switch will make 20 steps, each lamp glowing 10 times. If, however, it is desired to test response on both lamps and eliminate the discrimination factor, both A and B keys may be thrown. In that case the earth of the switch drive circuit is removed after 10 steps. Thus the utility of the instrument is extended without any added complication or sacrifice of simplicity.

*S*3 *arc* varies the interval between tests, namely that between successive lamp-glows, by variation of the resistance inserted in the release circuit of the relay A. Increase of series resistance, by absorbing energy otherwise available at the relay, shortens the time required for the relay to reach its release point and hence decreases the time-interval.

Accuracy

For simple comparative purposes, absolute accuracy is of less importance than reliability and consistent operation; these two qualities are ensured by the known performance of the components under the exacting conditions of telephone switching service. The absolute degree of accuracy and the exact effect of each possible source of error were not determined, as the very considerable work entailed was not justified; but consideration was given to the various possible sources of error.

While the instant of switching-on of the lamp can easily be determined from an oscillogram, it is not so easy to determine how long current must flow before the light will be visible. Experimental work was done on this problem, using a photocell in the grid circuit of a thermionic valve, the anode circuit having an oscillograph loop in series. It has not been possible to complete this experimental work, owing to the war-time difficulty of obtaining a particular lamp, but the results show that the time taken can be made approximately equal to the time a relay takes to operate. The time has been minimized by using a metal-filament gasfilled lamp; and the method of energizing the lamp, shown in Fig. 2 to be by 50-volt battery with 1 000 Ω in series, may be modified so as to give better results. The slip of the timing mechanism under the brake is so small as to be undetectable by ordinary measurement, and can be considered negligible. Lost motion in the gearing is a small fraction of one tooth and occurs but once in a cycle; it is barely perceptible even when looked for, and is in itself insignificant. The operating and release times of relays and magnet were studied as far as they affect the timing operation. Oscillograms have also been taken showing the switching conditions in the lamp, key and timing-mechanism circuits, all on the same time-base; from these oscillograms the timing mechanism was calibrated.

As the operate and release lags of the timing mechanism, being equal, cancel one another, the record is merely displaced in time; it is unaffected in accuracy.

CO-ORDINATION TEST

Here the candidate is required to associate a coloured-lamp signal with a press-key in a small keyboard. Four colour-lamp signals, irregularly spaced so that the eye has to move a little up, down or sideways to look at each, are

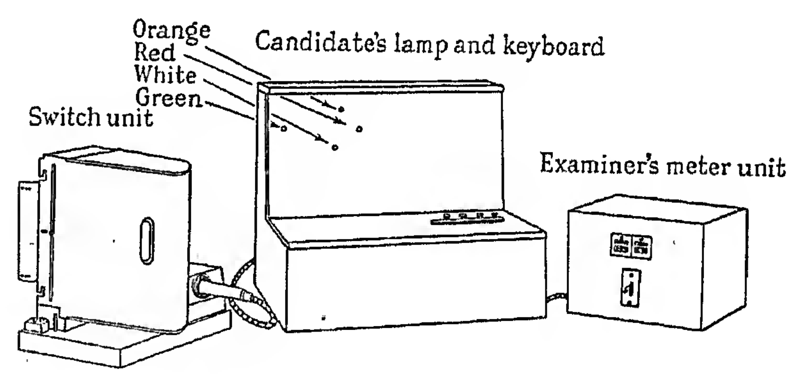

Fig. 3.—Co-ordination tester.

placed in front of the candidate. The latter is provided with a keyboard with four press-keys in a row so that they lie conveniently under the four fingers of one hand. Each key is associated with one of the lamps, which are arranged so that their relative positions are not in accord with those of the keys (Fig. 3).

The candidate is required momentarily to depress the key appropriate to the lamp signal displayed on the panel. The depression of the key extinguishes the signal, and upon the release of the key the next lamp signal appears. The lamps are lit in a predetermined irregular sequence which repeats only after 100 signals. As the candidate may start at any point in the cycle of signals, and successive practice and test runs are unlikely to start from the same point in the cycle, even the most intelligent and observant is unlikely to recognize the sequence and so bring memory to bear to anticipate the signals.

The examiner has a small unit containing two meters and a " start" key for switching-in the meters at will.

One meter records the number of times the correct key has been depressed by the candidate in response to a signal, and the other the total number of operations within the period of test. The switch-and-relay mechanism is arranged to be placed at a sufficient distance to avoid disturbance by any sound which might otherwise reach the candidate.

The conduct of the test is quite simple. The candidate is instructed in the use of the keys and, in the first instance, at least, is furnished with a colour indicator for the keys. The candidate is then asked to continue operating until stopped, and is encouraged to work as fast as possible consistent with accuracy. When the examiner considers that the candidate is operating steadily enough to warrant a test, he throws the "start" key and also starts a stop-watch. The meters are then connected and register total and correct key operations. The equipment is so arranged that the depression and release of any key will bring the next signal before the candidate and operate the "total" meter, but only the correct key will operate the "correct" meter. At the end of the chosen time-period, as indicated by the watch, the "start" key is restored and the meters are read.

At the end of a test run the candidate is allowed a rest pause and suitably encouraged to give a better performance on the next run. The authors found that three such tests, each recording for 1 minute, were sufficient to give results satisfactory for the purpose in mind. The total test time involved depends, of course, upon the confidence of the candidate and the art of the examiner in inculcating it.

The complete operation sequence can be followed upon the circuit diagram, Fig. 4. Completing the battery supply to the instrument causes the lamp appropriate to the position of the uniselector switch to be lit. The candidate then extinguishes the lamp by operating a key, the next lamp in sequence (it may, of course, be the same lamp) is lit, and this is repeated indefinitely. The record circuit functions during the time the "start" switch is closed. For the switch position shown in the diagram the red-lamp circuit is completed via No. 1 contact of arc No. 1 and relay contacts Y4.5.

The candidate presses the "Red" key and thereby (*a*) applies earth to the "Red" contacts on switch arcs Nos. 3, 7, 4 and 8, and thus operates the "correct" meter via arc No. 3 if the "start" key ST on the control panel

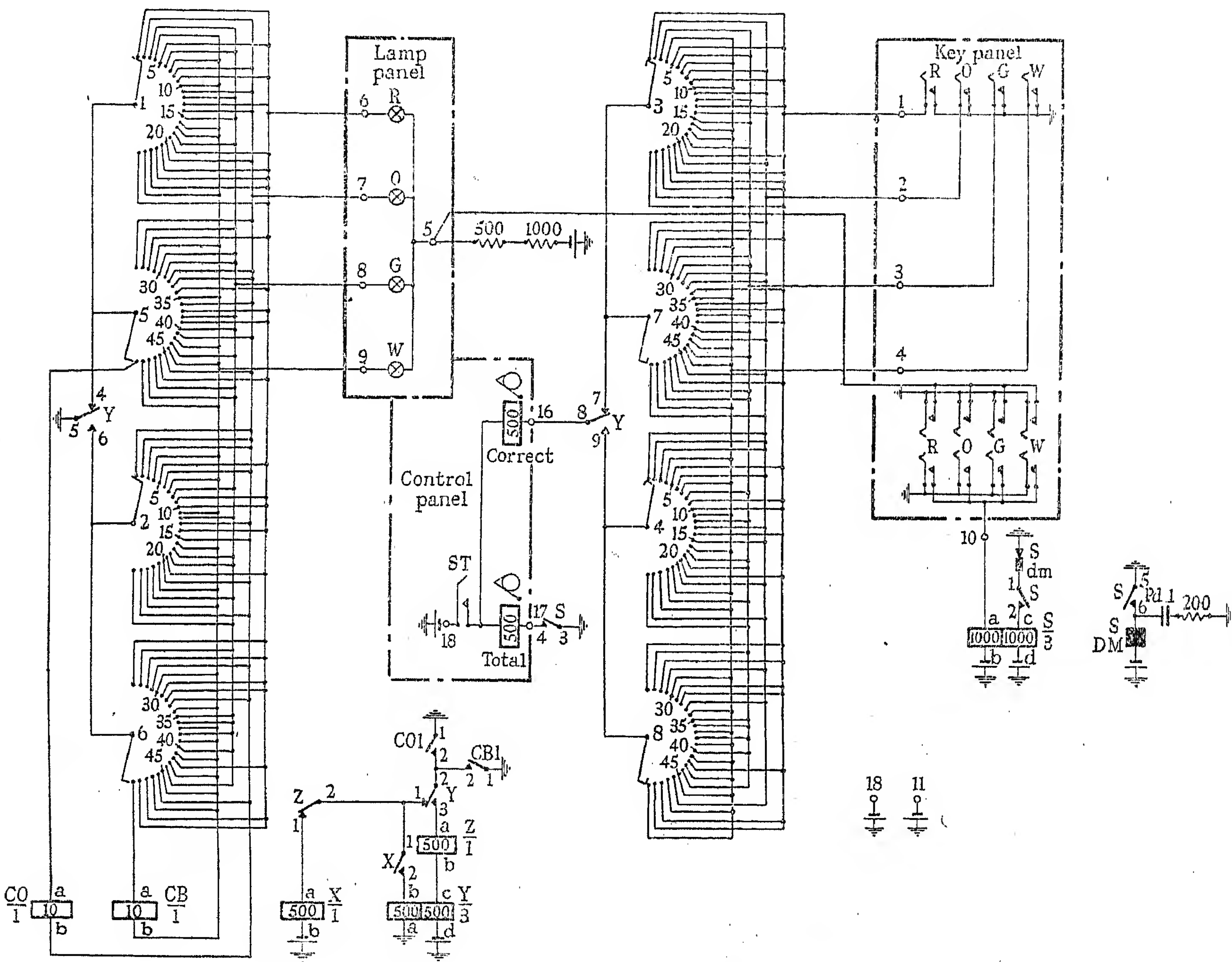

Fig. 4.—Co-ordination tester.

is closed; (*b*) applies earth to the lamp panel and thus extinguishes the lamp by short-circuit; (*c*) applies earth to the main winding circuit of relay S, causing that relay to operate. [It will be seen that the depression of any key, correct or incorrect, will perform functions (*b*) and (*c*).]

Relay S then operates. Its self-locking winding is energized via its own contacts S1.2 and if the "start" key has been operated the contacts of the switch driving magnet S3.4 complete the circuit for the "total" meter. S5.6 completes the circuit of the switch driving magnet SDM. The switch driving magnet operates and disconnects the hold coil of relay S at Sdm.

If the candidate has released the key, or when it is released, relay S releases, the driving-magnet circuit is interrupted at S5.6 and the switch steps on to the next contact. The lamp appropriate to that position glows and the cycle of operations is repeated.

It will, of course, be appreciated that as all the wipers are rigidly fixed to the driving spindle of the uniselector, the wipers of arcs Nos. 1, 2, 3 and 4 and similarly of Nos. 5, 6, 7 and 8 make their respective contacts in unison, the two groups being displaced by 180°, giving a 50-point switch.

A subsidiary control circuit is provided to give this standard 50-point switch 2 revolutions per cycle of signals, and thus obtain in effect a 100-point switch. The operation is as follows: When the switch reaches contact No. 50 of arc No. 5, the circuit of relay CO is completed via Y4.5, arc No. 5 (contact No. 50), CO ab and lamp O. Relay CO operates and completes the circuit for relay X via Z1.2, Y1.2 and CO1.2. Relay X operates, closes X1.2 and thus prepares a circuit for relay Y on removal of earth at CO1.2.

When the candidate releases the press-key at this 50th arc contact-point, the switch steps as previously described, thus releasing relay CO and removing the earth at CO1.2. Relay Y operates in series with relay X via Y ab, X2.1, Z2.1 and X ab, and closes Y5.6, thus changing the switching to arcs Nos 2, 4, 6 and 8. When the 100th step point has been reached, relay CB operates. Relay Z operates via CB1.2, Y2.3, Z ab, Y cd, and so releases relay X by breaking the circuit at Z1.2. When the switch steps, relay CB is released, the earth at CB1.2 is removed and relays Y and Z release. Contacts Y4.5 close and the switching is then back on arcs Nos. 1, 3, 5 and 7, ready to repeat the sequence.

The fitting of reset meters is a refinement which assists the examiner. As expected, the switching time proved to be negligible compared with the response of the candidate, and it can therefore be ignored. It is not possible to distinguish by eye any lag between releasing the press-key and the next lamp signal.

A good performance is of the order of 50 operations per minute, and unsatisfactory candidates are fairly obviously indicated by the test figures alone, without the added observations of the examiner on faults, method of operation, concentration, etc.

RESULTS

A short description of the results obtained may be of interest. The first results had to be regarded as experimental, since there was no standard of performance on the machines with which they could be correlated. They will only be of full value when the performance of the first operators is known, and when it is established that candidates recording scores between certain limits are likely to make good operators. As a first step in evaluating the results, the distribution curves shown in Figs. 5 and 6 were plotted; they show how the scores varied among the

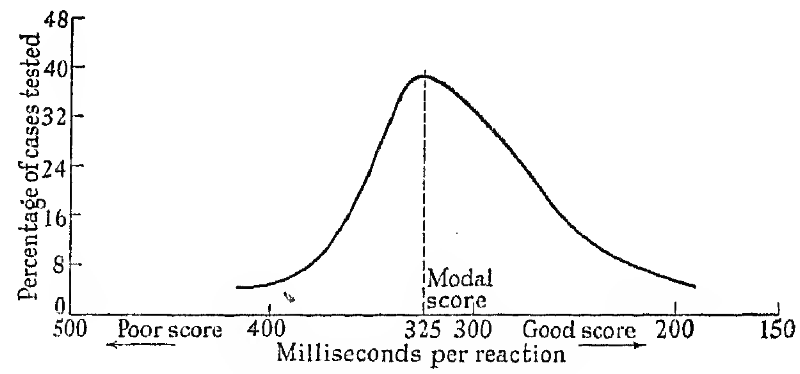

Fig. 5.—Distribution curve.

groups of candidates tested, and from them the modal scores, or scores reached by the largest number of candidates in the groups, are obtained.

The distribution curves form the basis for grading future results. The distribution curve in Fig. 5 shows that the normal reaction time for the test group is of the order of 325 milliseconds.

As a matter of interest, a number of tests were made outside the group and included members of the laboratory staff; the results were within the same range, and it appears evident that to average 200 milliseconds is approaching the limit.

Observation showed that where a good score is returned, the individual reaction times closely approach the average of the ten, but a poor score usually consists of more erratic individual times. Similar tests for co-ordination, however, showed that much better scores than those of the group were possible. It is of course to be expected that both intelligence and certain types of training will show to advantage in a test of this nature.

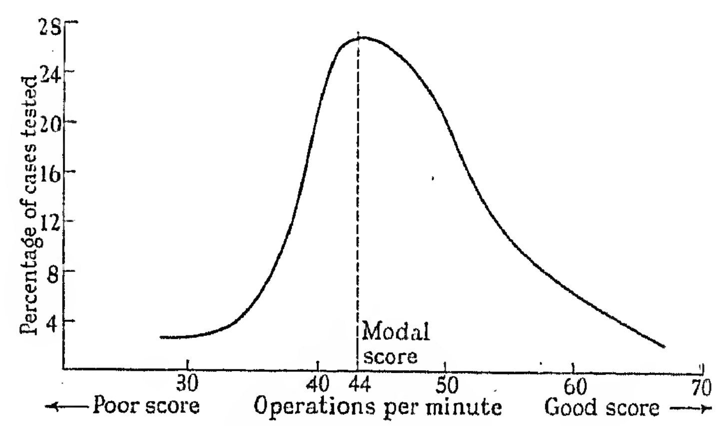

Fig. 6.—Distribution curve.

It is seen that the modal score does not lie midway between the extremes, but is nearer the lower end of the range. A lower-limit score must be fixed, probably a little below the modal score, and candidates scoring below this limit would not be accepted, since they would not possess the required natural ability, and to attempt to train them would not be in the best interest either of the candidates themselves or of the department concerned. On the other hand, there is obviously no upper limit for a suitable score,

and the ideal would be to take only those candidates with high scores. A compromise must be made, however, since the graphs indicate the percentage of candidates who are likely to reach any given score, and therefore the acceptance limits must be set with reference to the available supply of candidates. It will be appreciated that the results of other tests play their part in the selection of suitable candidates.

CONCLUSION

The two testers described were intended to test simple psychological factors by natural, easily-understood actions on the part of the candidate. It is usual for candidates to find interesting the tests for qualities or abilities which they possess; indeed, they often enjoy such tests. This was also found to be the case here.

The testers gave results which adequately fulfilled their immediate purpose.

The test equipment employs only simple electrical switching operations with standard telephone relays, switches and keys, while the subsidiary components are similarly standard telephone parts. The reliability of performance is therefore of a very high order.

It is felt that the reaction tester provides an accurate yet relatively inexpensive tool for a measurement of importance in many cases, and is usefully applicable to candidates for a variety of occupations.

Though the co-ordination tester is obviously more limited in application, it may well serve to stimulate thought in regard to the simple solution of other test problems on parallel lines.

ACKNOWLEDGMENT

The circuits were designed by Mr. B. A. Green, to whom the authors tender grateful acknowledgment.

ABSTRACTS OF PAPERS

THE VALIDITY OF LIGHTNING TESTS WITH SCALE MODELS

By R. H. GOLDE.

(ABSTRACT *of a paper* which was published in April, in Part II of the Journal.*)

Since Franklin's introduction of the lightning rod it has been generally agreed that the protection of structures from lightning strokes is best effected by their interception and safe discharge to earth. While this principle has been proved correct by long years of experience, the area protected by such devices is still under discussion. Engineers have tried for many years to study the problem by subjecting scale models of protective devices to artificial sparks in order to avoid the long delay entailed in the accumulation of statistical data from field observations. It is the object of the present paper to consider whether such tests can be expected to yield correct results.

It is now known that a lightning stroke is initiated by the so-called leader stroke which starts from the cloud and, on reaching the earth, is followed by the heavy return stroke flowing up towards the cloud. It has recently been shown that laboratory sparks produced by surge generators are similarly initiated, but there is an important difference between the mechanisms of these discharges in the natural and artificial cases. In the laboratory, surge voltages of such magnitude are required for these model tests that invariably upward streamers develop from the earth electrode, and these meet the downward leader stroke somewhere in mid-space. These streamers increase artificially the height of the test object and produce a "guiding" effect for the downcoming leader. In nature, on the other hand, the downward leader stroke bridges practically the whole distance from cloud to earth, and streamer discharges from earthed objects, such as lightning conductors, are so short compared with the total length of the lightning channel that their influence on the track followed by the leader is very slight.

It therefore follows that artificial tests are misleading and that results obtained in the laboratory cannot be applied directly to cover the natural case. This is confirmed by the fact that while artificial tests suggest that the space protected by a vertical rod is given by a cone having its apex at the top of the rod and a radius considerably greater than the height of the rod, statistical observations of buildings damaged by lightning show that the radius of the protected area is at the most equal to the height of the lightning conductor.

* Official communication (Ref. S/T38) from the British Electrical and Allied Industries Research Association.

MATERIALS FOR ELECTRICAL CONTACTS

By J. C. CHASTON, Ph.D.

(ABSTRACT *of a Meter and Instrument Section paper† which will be published in August, in Part II of the Journal.*)

The principal causes of failure of electrical contacts of the make-and-break type in circuits carrying currents not exceeding about 15 amp. are summarized in Table 1. It is convenient to consider separately the behaviour of (*a*) light-duty contacts, which operate in conditions where no arcing or electrical wear occurs, and (*b*) medium-duty contacts which may be subject to material transfer, pitting or welding.

LIGHT-DUTY CONTACTS

In these applications, development of a high contact resistance is the greatest cause of trouble. In general, the size, shape or surface finish of contacts does not greatly influence contact resistance, but the following steps are recommended to reduce to a minimum troubles from dust and from surface films of foreign matter:—

(*a*) The use of as high contact pressure as possible.

(*b*) The use of highly polished contact surfaces, with at least one dome-shaped contact; contacts may with advantage be mounted as "twins" on a split spring.

(*c*) The installation of dust covers and the arrangement of springs as far as possible in the vertical plane.

Tarnishing of the contact surfaces may occur through the formation of more or less complex oxides or sulphides, according to the nature of contact material. Table 1 lists a number of the commoner contact materials according to their resistance to tarnishing. Complete resistance to tarnishing in all conditions is possessed only by platinum, which can be regarded as a standard to which all other contact materials should be referred, by the soft and seldom used metal, gold, and by alloys rich in these two noble metals, such as the hard iridium-platinum alloys, the ruthenium-platinum alloys containing not more than 5% ruthenium, and the widely used 7:67:26 platinum-gold-silver alloy. Bright rhodium electro-deposits and the rather brittle noble metal iridium are nearly as tarnish-resistant, but oxidize if heated above about 900° C. A second group, nearly as tarnish-resistant, includes palladium, palladium-rich alloys, and alloys containing more than about 10% of ruthenium. These oxidize if heated above about 350° C. A third group comprises silver and silver-rich alloys. These are immune to oxidation but unfortunately are liable to serious tarnishing through the action of sulphur. In many positions they give excellent service; but, particularly in urban locations, they are not entirely reliable and in no case must they be used near rubber-covered wiring or ebonite. The fourth group are not suitable for light-duty work.

† Communication from the Research Laboratories of Messrs. Johnson, Matthey and Co., Ltd.

TABLE 1

Causes of Failure of Electrical Contacts

	Type of failure	Factors which may influence failure
A. Light-duty contacts (no electrical wear)	Development of high contact resistance	(a) Mechanical pressure between contacts; their size, shape and surface finish (b) Resistance of contact material to oxidation and tarnishing (c) Tendency for dust, grease films and adsorbed gases to form high-resistance films
B. Medium Duty Contacts:—		
(1) In d.c. circuits	Change in contact gap, often accompanied by seizure, as a result of material transfer	(a) Resistance of contact materials to material transfer under the operating conditions (see text) (b) Extent of contact bounce, which affects the real frequency of interruption
(2) In a.c. and d.c. circuits	Welding of contacts due to current surge at make	(a) Resistance of contact materials to welding (b) Unsuitable spark-quench circuits
(3) In a.c. circuits	Excessive wear on contacts	Principally resistance of contact material to oxidation

MEDIUM-DUTY CONTACTS

When contacts are operated in d.c. circuits, serious variations in the length of the gap may be caused as a result of material transfer; and in some instances the contacts may even become interlocked. At least three types of material transfer appear to exist:—

(a) With small currents, below a critical value (which is most probably that at which arcing commences), *negative transfer* may result in material being transferred from the positive to the negative contacts. In the author's experience this occurs only with currents just below the limiting value and is never sufficiently large in amount to be a serious cause of contact failure.

(b) With larger currents, when arcing takes place, *positive transfer* occurs, most probably at the instant when the contacts are separating. When no spark-quench device is fitted, the value of the limiting current for any material falls as the voltage rises and attains a minimum value at approximately 50 volts. Values for the limiting current have been determined for a number of materials, using batteries and a full-wave metal rectifier as source of current, with the results given in Table 2.

While these results suggest that the factors influencing limiting current are more complex than is often considered, they afford a guide for the preliminary selection of a contact material.

When the limiting current is exceeded, transfer may be extremely rapid and in some instances, as in pure resistance circuits operated from a battery supply, there is little difference to choose between various materials; though in other circuits, where transfer is less severe, there may be a more pronounced difference in their behaviour. Generally speaking, tungsten resists transfer better than any other material, but has the disadvantages that it may develop high contact resistance through the formation of oxide films, and that it cannot be riveted, cold-worked or welded. The composite silver-molybdenum and silver-tungsten materials are generally rather less resistant, but silver-nickel has advantages in some conditions. Among the tarnish-resistant metals, fine silver appears to resist transfer better than any other, but iridium-platinum and platinum are preferable in some rather narrowly defined conditions. The gold alloys are liable to transfer badly and most of the silver alloys are worse than silver, though some complex silver alloys, particularly those containing cadmium and magnesium, behave well in some circuits.

TABLE 2

	Limiting current	
	110 volts battery supply	110 volts, full-wave rectified direct current
	amp.	amp.
10 % gold-silver	—	0·4
Platinum-gold-silver ..	0·60	0·5
10 % palladium-silver ..	—	0·6
Fine silver	1·08	0·6
Palladium	—	0·65
40 % copper-palladium ..	—	0·7
Commercial platinum ..	—	0·85
10 % ruthenium-platinum	—	0·92
30 % iridium-platinum ..	1·65	1·1
Tungsten	—	1·7
70 % silver-nickel	1·0	None (but little transfer even with 1·8 amp.)

(c) A third type of transfer is sometimes found in circuits in which a spark-quench condenser is fitted. If insufficient resistance is placed in series with the condenser, there may be a current surge at make which produces in effect a spot weld. When this is broken, the negative contact may pick particles from the positive and produce an appearance of *negative transfer*.

TABLE 3

Common Contact Materials—Classified According to their Resistance to Tarnishing

Material	Approximate hardness of annealed materials. Vickers pyramid hardness numbers	Remarks
Group A.—Completely resistant to tarnishing.		
Pure platinum	39	
Commercial platinum	68	
Rhodium (electro-plated)	—	Tarnishes above about 900° C.
Iridium-platinum—10 % Ir	110	
20 % Ir	200	
25 % Ir	250	
30 % Ir	290	
Ruthenium-platinum—5 % Ru	130	
Platinum-gold-silver—7:67:26	70	
Gold-silver—70 % Au	72	
Pure iridium	420	Tarnishes above about 900° C.
Pure gold	23	
Group B.—Resistant to sulphide tarnishing. Liable to oxidation at temperatures above about 350° C.		
Palladium	63	
Copper-palladium—60 % Pd	130	
Silver-palladium—50 % Pd	84	
Ruthenium-platinum—10 % Ru	195	
14 % Ru	245	
Group C.—Resistant to oxidation. Liable to sulphide tarnishing.		
Fine silver	23	Probably best all-round contact material
Gold-silver—5 % Au	27	Little, if any, more resistant to tarnishing than fine silver
10 % Au	28	
30 % Au	37	
Palladium-silver—5 % Pd	33	
10 % Pd	40	
20 % Pd	55	
Copper-silver—$7\frac{1}{2}$ % Cu	50	Slightly more liable to tarnishing than fine silver
10 % Cu	75	
20 % Cu	108	
Group D.—Liable to oxidation, sulphide tarnishing, or both.		
Tungsten	290	
Silver-tungsten	210	
Silver-tungsten carbide	100	
Silver-molybdenum	175	
Copper-tungsten	137–290	
Silver-nickel	—	
Silver-graphite	—	

WELDING OF CONTACTS AND WEAR IN A.C. CIRCUITS

A measure of the inherent tendencies of contact materials to weld can be obtained by observing the minimum resistance which must be placed in series with a spark-quench circuit to prevent sticking. Table 4 gives some of the results that have been obtained.

The materials most resistant to welding are, as might be expected, tungsten and related powder-metallurgy products; whereas platinum and platinum alloys are particularly prone to sticking. In a.c. circuits a general uniform roughening of the contact faces is produced, and fine silver appears a suitable material in most applications, although for utmost reliability platinum is to be preferred.

SLIDING CONTACTS

The wear resistance of a number of combinations of tarnish-resistant and some base metals has been studied by a device in which the length of the channel produced in a

TABLE 4

Welding Characteristics of Contact Materials

Material	Series resistance needed to prevent welding
	ohms
Elkonite 10 W 3 (copper-tungsten)	1
Elkonite G 17 (silver-molybdenum)	
70 % silver-nickel	
10 % gold-silver	7
Fine silver	9
40 % copper-palladium	10
Elkonium 61 (Mg-Cd-Ag)	12
30 % silver-gold	
Fine gold	15
Platinum-gold-silver	17
Palladium	18
Commercial platinum	25
20 % iridium-platinum	37

flat plate by a revolving wheel is measured. The results obtained are given in Table 5.

TABLE 5

Material of wheel	Material of plate	Length of channel
		mm.
15-carat gold alloy	Rhodium plate	0·3
15-carat gold alloy	15-carat gold alloy	0·4
Nickel brass	Nickel brass	0·45
Phosphor bronze	Phosphor bronze	
Phosphor bronze	Nickel brass	0·5
15-carat gold alloy	Standard silver	
Fine silver	15-carat gold alloy	
Fine silver	Rhodium plate	
Rhodium plate	Rhodium plate	0·6
Nickel brass	Phosphor bronze	
Rhodium plate	15-carat gold alloy	0·65
Fine silver	Standard silver	0·7
Rhodium plate	Standard silver	0·8
15-carat gold alloy	Fine silver	0·85
Fine silver	Fine silver	1·0
Rhodium plate	Fine silver	1·3

Thus the use of rhodium plate with 15-carat gold rubbing contacts appears well justified.

OUTDOOR BUSHINGS, THEIR CONSTRUCTION, TESTING AND STANDARDIZATION

By W. A. COOK, B.Sc.(Eng.), Associate Member.*

(ABSTRACT *of a Transmission Section paper which will be published in August, in Part II of the Journal.*)

An outdoor bushing is a piece of apparatus which insulates a conductor passing through an earthed barrier, one end at least operating outdoors without cover. Outdoor bushings are exposed in service to the risk of mechanical damage due to accident or operation of the associated apparatus, and to electrical damage due to over-voltages or atmospheric pollution. Ease of replacement, which involves some degree of standardization, is therefore an important matter. This paper surveys present practice in construction and the test specifications controlling design and hence makes suggestions regarding the lines upon which the problem of standardization should be attacked.

An outdoor bushing usually has an enclosure of porcelain or other ceramic material incorporating rain sheds, but toughened glass promises to give mechanical advantages if the present limitations in size can be overcome. This enclosure may either extend through the earthed metal and form all or part of the radial insulation, or cover the outdoor end of the bushing only. If the whole of the bushing between conductor and flange be of a single material, the radial voltage gradient will fall away from the conductor as shown in Fig. 1(*a*). Such a simple construction may be applied for voltages up to 11 kV, the inside surface of the porcelain or glass shell being metallized and connected to the central conductor to avoid stress in the intervening space. For higher voltages, the usual arrangement is a combination of solid and fluid insulating materials surrounding the connector and enclosed, at least at the outdoor end, by porcelain. In such cases there is a tendency for the radial gradient to be higher in material of lower permittivity, such as air or oil, than in solid materials such as bakelized paper or porcelain. Typical effects are shown in Figs. 1(*b*) to 1(*g*).

Besides fulfilling the insulating requirements, a bushing must provide for the expansion of any liquid or plastic filling material; for the different expansions of the various solid components which may be due either to different coefficients of expansion or to non-uniform distribution of temperature; and the porcelain shell must be secured without introducing concentrated mechanical stresses which might lead to fracture. At the lower voltages a solid porcelain bushing and, in some cases, other ceramics or glass, or an oil-filled or compound-filled porcelain with no internal solid insulation are widely used owing to their simplicity. At 22 kV, and sometimes at 11 kV, some internal solid insulation becomes necessary, and then a bushing of the bakelized-paper non-condenser or condenser type may be considered as an alternative to the oil-filled or compound-filled porcelain with a conductor partly insulated with bakelized paper. An oil circuit-breaker bushing may have to be reinforced to withstand heavy mechanical forces at the bottom end owing to operation of the breaker, and this end must be long enough to pass through the air space at the top of the tank and also have sufficient creepage distance under oil.

For circuit-breakers between 33 kV and 88 kV a bakelized-paper condenser-type insulator has been found to be very satisfactory, with a closely fitting porcelain surrounding

* The Bushing Co., Ltd.

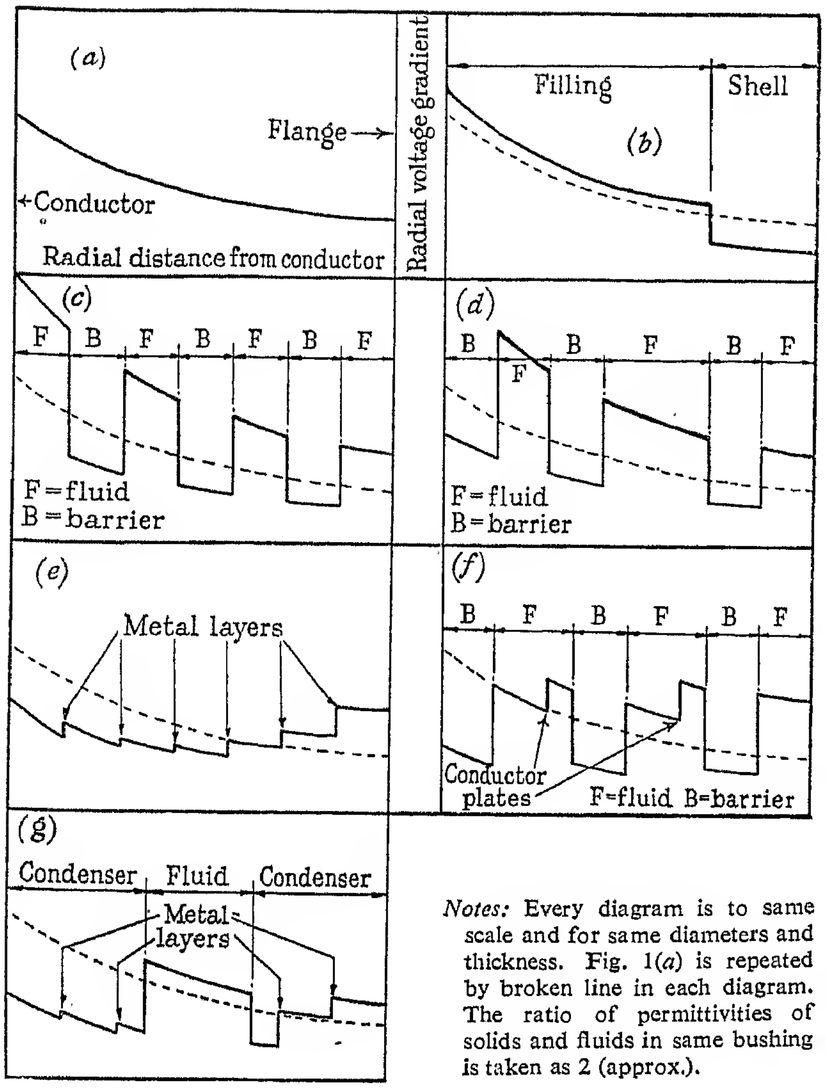

Fig. 1.—Stress distribution in bushings of various types.

(a) Single dielectric.—e.g. all-porcelain bushing with close fitting inner electrode.
(b) Shell filled with fluid, plastic or solid—e.g. air, oil or compound filled porcelain.
(c) Barrier bushing (fluid next conductor)—e.g. oil filled porcelain with barriers of bakelized paper, porcelain, etc.
(d) Barrier bushing (solid next conductor).
(e) Condenser bushing—e.g. bakelized paper or micarta with inserted metal layers. The outer shell has no radial gradient.
(f) Barrier condenser bushing—e.g. as (c) with intermediate metal tubes.
(g) Divided condenser bushing—e.g. as (e) with middle portion replaced by oil.

the outdoor end, the space between being filled with a thin film of hard bituminous compound introduced under pressure from the flange end. Manufacturing difficulties impose a limit of about 88 kV to this construction, and above this voltage fluid filling, providing greater freedom for expansion, is to be preferred. A larger space may then be allowed between bakelized paper and porcelain, filled with semi-fluid oil, which is allowed to expand in a sealed expansion dome; or if the inclusion of current transformers involves the filling of a large space, transformer oil may be used with syphon expansion. The oil as it expands then escapes through the central conductor into the circuit-breaker tank and it syphons back into the bushing as it contacts.* For transformers rated between 33 kV and 132 kV, bakelized paper condenser-type internal insulation may again be adopted. In this case oil filling is easily provided by means of communication from the transformer conservator. The bushing is then maintained completely full of oil a little above atmospheric pressure, and no damp air can therefore be drawn in. Excessive escape of oil following porcelain fracture can be avoided by making the communicating channel small, and by providing it through the central tube rather than through the flange. Lowering of the oil level in the transformer, and so exposing the windings when connecting them to the bottom of the bushing, may be avoided by means of a flexible cable, attached to the winding, which may be drawn through the central conductor, then of tubular form, and secured within the top cap. To allow this bushing to be transported without removing all the oil, the communication through the tube may be covered by a temporary seal. Above 132 kV the manufacture of a single condenser bushing may be impracticable or uneconomical and then two concentric condensers in series may be used, with one of the types of oil-filling already described. Alternatives worthy of consideration for such high voltages are the barrier condenser type, in which the oil space between conductor and flange is divided by a number of concentric bakelized paper tubes (or other similar material) interspersed with a number of metallic tubes. Concentration of stress at the ends of the metal tubes can be avoided by belling them and attaching insulated metal rings just beyond the ends. Such a bushing acts on a well-known condenser principle, and is a compromise between the normal bakelized paper condenser bushing and the barrier-type oil-filled bushing.

Most outdoor bushings are used with the conductor connected to one phase and the flange to earth on a 3-phase system, and usually—particularly above 33 kV—with the neutral of the system earthed sufficiently solidly to prevent the voltage on the bushing from rising for any length of time. Such bushings have to withstand the working voltage of the system divided by $\sqrt{3}$, with due allowance for regulation variations and any switching or lightning surges passed from the line. With a bushing of porcelain alone the design is largely settled by the second requirement, whilst with a bakelized-paper condenser the controlling factor is often, but not always, the first.

When the system employs Petersen coils or other devices which allow the neutral to take up a high potential, it becomes necessary to consider systems in which the fault is cleared in a comparatively short time (i.e. a few hours), and also systems which continue to operate for extended periods with one line earthed. In the first type normally-designed bushings will perform satisfactorily, whilst in the second type the bushings must be designed to work continuously at the full-system voltage. They will consequently be larger, particularly in diameter, to an extent depending upon the type of bushing. Bushings of porcelain alone will be little larger, but other bushings need to be increased by varying amounts depending upon the type and conditions.

The essential purpose of testing bushings is to obtain evidence that they will withstand satisfactorily these service conditions. This can be achieved ideally by the following tests:—

(a) A routine test to ensure that no dangerous degree of ionization or discharge occurs in any part of the dielectric at a voltage sufficiently above the working phase voltage to cover regulation variations. By "routine test" one on all or a proportion of the bushings is intended, the proportion depending upon the degree of uniformity which may be expected. The power-factor/voltage test fulfils this function, the knee-point on the curve denoting

* ALLAN, British Patent No. 253189.

that ionization has reached a stage at which damage may develop. Detectors have been devised which observe the high-frequency oscillations produced by ionization in the current through a bushing. The main drawback to the general use of such devices is the response of apparatus highly sensitive to ionization at a very low voltage, with insulators that experience has proved to be completely satisfactory. This makes it necessary to define the amount of innocuous indication that is permissible, and to be able to determine when this amount is exceeded. So far these essentials have not been achieved. The indication of ionization given by a power-factor/voltage test does appear, from experience, to correspond to the degree of ionization which may develop serious trouble in service. There is, nevertheless, reason to believe that bushings failing even this test may survive service conditions, and many bushings have operated successfully for many years, although they were made in the days before power-factor tests were used. Discharges are more likely at low temperatures owing to the lower pressure, and consequently lower breakdown, voltage in any void; 30° C. is therefore a convenient basis for tests. A voltage margin of 10 % to 20 % over phase voltage is suggested.

(*b*) A test to ensure that the dielectric losses ultimately reach equilibrium (the thermal equilibrium voltage) at a sufficient margin above the working phase voltage. A power-factor/time test serves this purpose, and should be conducted with the highest external temperature met in service. There is little logical reason why the voltage margin should exceed 10 % to 20 %, except the suggestion that any absorbed moisture may subsequently increase the losses. Apart from extreme cases, however, the losses are more likely to expel the moisture. Nevertheless, a margin of 75 % to 100 % is commonly employed, as it presents no special difficulty. Thermal breakdown is of very infrequent occurrence with modern technique, and a percentage test suffices in most cases.

(*c*) A type test to ensure that the bushing is not damaged by an impulse voltage of the severest form which can be passed to it. Whilst impulse flashover tests can be made without difficulty, no simple way has yet been developed for detecting with certainty the incipient damage which they cause to the dielectric, and therefore such a test cannot yet be regarded as a sufficient guarantee of the breakdown value of the insulation. It is therefore necessary to depart from the ideal, and employ instead 50-cycle flashover-type tests: wet, as an indirect measure of the minimum voltage at which the bushing will flash over in service; and dry, as a measure of the maximum voltage to which the bushing may be subject; and in oil, as a measure of the voltage below which it will not fail internally. The essential requirements then are that the wet flashover value must not fall below a specified figure; and the margin between the dry flashover and the breakdown voltage in oil must be adequate. The specification of a minimum dry flashover voltage is without any logical basis, since it is the wet value which limits the suitability of a bushing. It would be better to specify a maximum dry flashover voltage, with the proviso, which is automatically obeyed, that it must be greater than or equal to the wet flashover value. Fig. 2 depicts graphically the values and effects of various tests.

Ionization may be assumed to occur when the maximum voltage gradient in a radial direction exceeds a certain

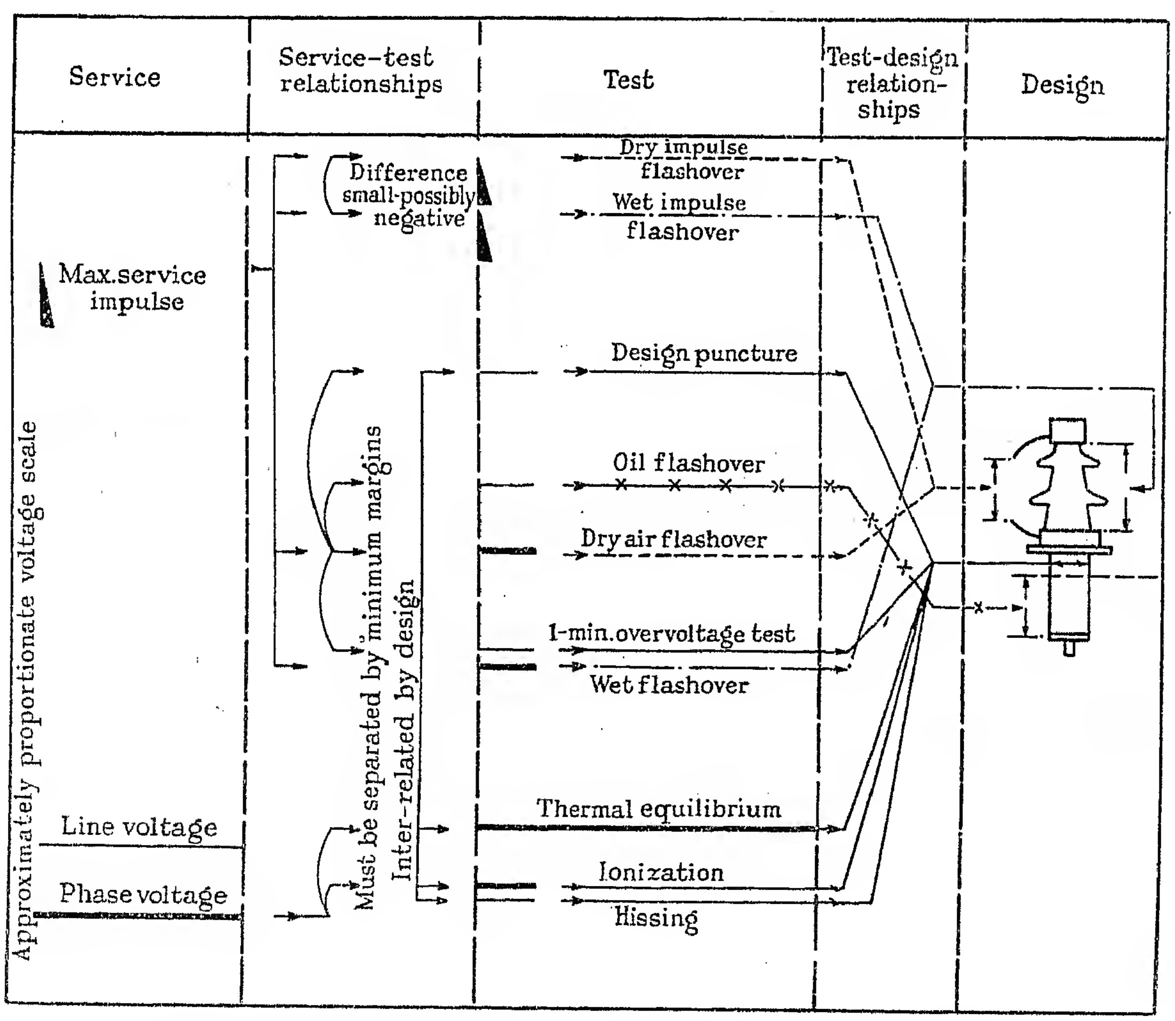

Fig. 2.—Relationship between service, test and design conditions.

limiting value depending upon the type of construction of the bushing and the quality of the materials employed. Thermal equilibrium usually imposes no additional conditions upon the design unless the construction hinders cooling to an unusual extent, as in the case of an insulator of exceptionally large capacitance surrounded by hard compound; or unless the bushing operates at an unusually high temperature; or if the materials are of indifferent quality. The equilibrium voltage depends only partly upon voltage gradient, and largely upon the relationship between cooling surface and bulk of material. With good-quality bakelized paper, thermal equilibrium has to be considered seriously only when voltages of 132 kV and temperatures of 80° C. are approached simultaneously. Flashover values, whether impulse or 50-cycle, control the clearances. The dry value depends upon the arcing-horn gap, and the wet mainly upon the total direct porcelain length. These flashover values also act as a second controlling factor upon the thickness of insulation, since the bushing must be designed not to puncture during flashover. The relative importance of flashover value and ionization value upon the thickness of insulation depends upon the type of construction. With a bakelized-paper condenser, the ionization value usually governs the design except at the lowest voltages. With bushings which rely mainly upon oil for the internal insulation—such as the barrier type—the flashover values become of relatively greater importance.

The electrical tests now commonly adopted include:—

(*a*) The over-voltage pressure test which furnishes a quick check of major defects but tends to increase minor ones, particularly in materials having a noticeable time-voltage characteristic such as bakelized paper. B.S. No. 223 requires a margin between test and flashover values of 11 % to 27 %.

(*b*) The 1-minute design puncture voltage. B.S. No. 223 does not differentiate between different modes of breakdown when the bushing is completely under oil, and only requires the breakdown value to be 15 % above the dry air flashover voltage. Other authorities consider it necessary for oil flashover to precede puncture, but since both destroy the bushing this is difficult to justify. It may be argued that a high puncture value is evidence of a high safe working voltage, but a test in proximity to the working voltage—such as an ionization test—is better evidence.

(*c*) An absolute measurement of power factor is of little significance. It is only of value when considered in the light of the customary values obtained with the particular grade of material, or previous values for the same bushing.

(*d*) The "hissing" or audible discharge test which is sometimes specified, particularly on bakelized-paper condenser-type bushings, may have one or both of two purposes. It may be intended to avoid noise which might lead an operator to feel uncertainty regarding the safety of a bushing; or it may be intended as a means of indicating discharges occurring within voids in the insulation which may lead to failure. In the former case the only requirement need be that no noise occurs above a specified noise-level. In the latter case the problem arises whether all noise denotes discharges that will be detrimental in service, and whether all discharges that will be detrimental in service, will give rise to noise. The answer to the second question is probably in the affirmative, providing the listening arrangements are sufficiently acute, but that to the first question is undoubtedly negative. In the first place, audibility is subjective, depending upon the individual observer. It also depends upon the degree to which extraneous sounds are excluded from the test room. Other methods of observations have been proposed, involving amplification of the actual sounds or detection of the high-frequency oscillations induced by ionization, and these are capable of more exact repetition by different observers. Experience shows, however, that the more acute the detection becomes, the lower the voltage at which it is possible. It becomes clear that some form of disturbance may be observed, given sufficient sensitivity, well below working voltage, on insulators known to be of highest quality and far superior to others which experience has proved to be satisfactory over many years' service. It is therefore necessary to determine some maximum magnitude of disturbance—whether it be measured audibly or electrically—which is tolerable at the working voltage, or at a small margin above it. So far these problems have not been solved, and the only test which can at present justly claim to detect harmful discharges is the power-factor/voltage test.

(*e*) The direct-current test. There is no simple relationship between the effects of alternating current and direct current. The position may be briefly as follows:—

(1) With a number of dielectrics in series the voltage distribution may be entirely different, since with alternating current it is determined by capacitance and with direct current by resistance. In particular, surface leakage will control the distribution much more with direct than with alternating current.

(2) The voltage at which internal ionization occurs with direct current will be much greater than with alternating current, and the tendency will be for the voltage distribution to readjust itself to minimize the stresses on weak parts, whereas the a.c. distribution is maintained substantially unaltered despite any incipient local defects or leakages.

(3) Power losses in the insulation are less with direct current, owing to the absence of losses of the "hysteresis" type.

(4) Unless moisture has permeated the material uniformly, the current at the point where moisture is present will not rise appreciably with direct current as it does with alternating current, owing to the inverse resistance/temperature characteristic, but will fall owing to readjustment of the voltage. Hence a greater drying-out effect will exist with alternating current. Moreover, the fact that the current is unidirectional will tend to draw the moisture through the insulator. For these reasons the effect of moisture will be very much more pronounced with direct current.

This means that direct current is less likely to develop those defects which tend to produce a.c. breakdown after a long time, i.e. time is of less importance with direct current. Summing up, the different voltage distribution may lead direct current to be more or less severe than alternating current to an extent very difficult to estimate. If the material is dry, direct current is otherwise considerably less severe than alternating current of the same crest value, particularly when long-time applications of voltage are

considered; and, if the insulation is damp, direct current may become more severe.

B.S. No. 223 has done much to stabilize basic test values, but it would be to the advantage of all concerned if the specification were more widely adopted. It suffers from the limitation that the tests included are not alone sufficient to ensure the suitability of bushings for service, particularly those employing materials with a pronounced time/voltage characteristic. It is neither practicable nor desirable to attempt any standardization of the construction. The number of purposes for which transformer and circuit-breaker bushings are made might, however, be reduced to the following:—(*a*) a transformer bushing without current-transformer accommodation; (*b*) a transformer bushing with current-transformer accommodation; (*c*) a circuit-breaker bushing for low and medium breaking capacities; (*d*) a circuit-breaker bushing for high breaking capacities which demand mechanical reinforcement. The draw-through type of transformer bushing connection is widely favoured and might well be adopted. Types (*b*) and (*c*) could simply be made identical by designing the metal tube, through which the flexible cable is drawn when the bushing is used on a transformer, to carry the current itself when the bushing is used on a circuit-breaker. When applied to a transformer, the current transformer could be housed in a chamber attached to the bushing above the tank top, thus leaving the same length below the tank top whether the current transformer is used or not. In the case of a circuit-breaker, the air-cushion space will usually suffice for the current transformer, and it would then be unnecessary to alter the bushing except to support the current transformer.

In addition, it would be an advantage to standardize a range of current ratings for the various principal voltages, fixing centres, and the lengths of bushing within the transformer or circuit-breaker. In the case of the transformer bushings, the lengths and dimensions of the draw-through cable must be fixed to ensure interchangeability, and some uniformity in the length of accommodation necessary for current transformers would be a great asset.

THE FLUCTUATIONS OF SPACE-CHARGE-LIMITED CURRENTS IN DIODES

By F. C. Williams, D.Sc., D.Phil., Graduate.

(Abstract *of a Wireless Section paper which will be published in December, in Part III of the Journal.*)

It is well known that the anode current of a space-charge-limited diode exhibits a spontaneous fluctuation which is much less than that associated with a temperature-limited current. The reduction is conveniently expressed as the ratio of the mean-square value of the actual fluctuations to the mean-square value of the fluctuations of an equal temperature-limited current, and is denoted by A.

This paper describes the experimental determination of A for a set of four cylindrical diodes having a cathode diameter of 1·7 mm. and anode diameters of 4, 8, 12 and 19 mm., and numbered 1, 2, 3 and 4 respectively. The measurements were taken with an amplifier responding to a frequency band of 2 Mc./s. ± 1 kc./s. The results are first plotted as curves relating A to anode current (see Fig. 1). It is found that all the values give curves of similar shape, which are displaced to the right by de-

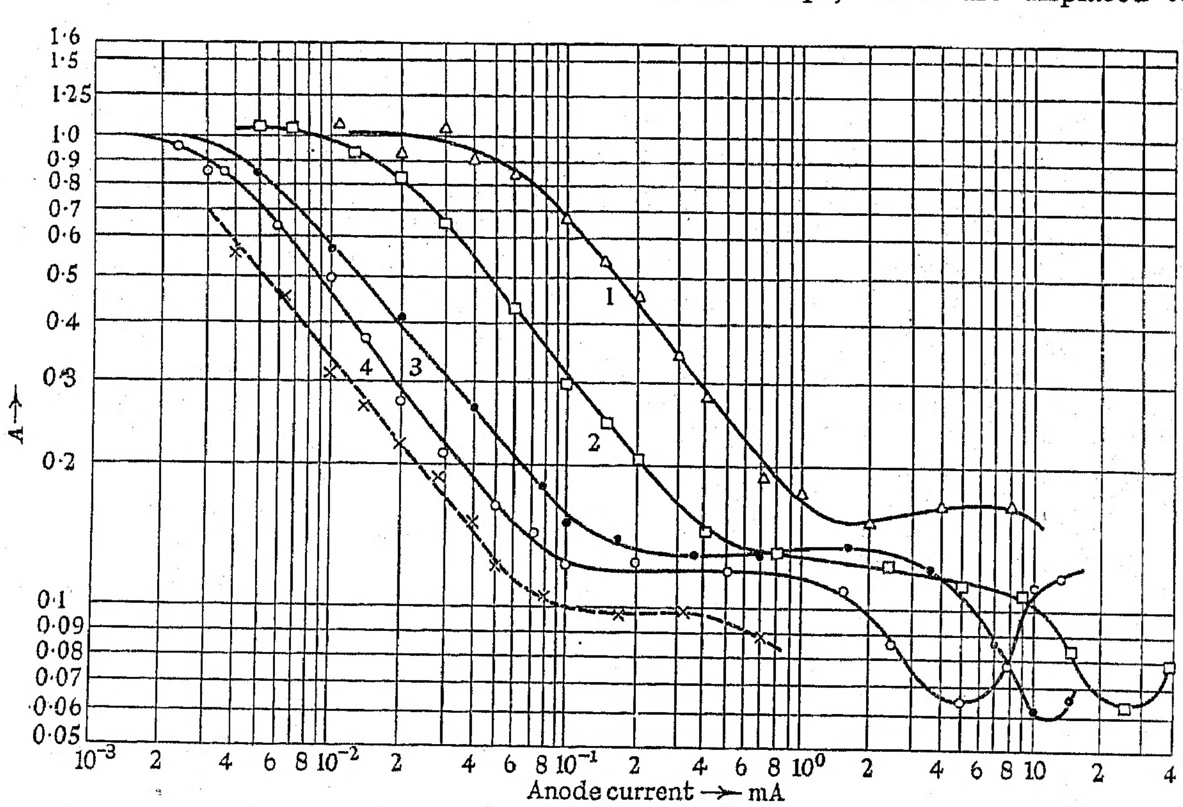

Fig. 1.—A as a function of anode current, cathode temperature constant except for the dotted curve, which relates to valve 4 with the heater voltage reduced to 2·4.

crease of anode radius and to the left by decrease of cathode temperature. A approaches unity at low values of current corresponding to retarding field conditions, and decreases roughly as $I^{-\frac{1}{2}}$ with high currents. When A reaches about 0·15 this smooth decrease ceases, and A fluctuates irregularly about the value 0·1 with further increase of I. This "flattening" is ascribed to some spurious effect such as collection of charge on, or secondary emission from, the glass or insulating micas: it is not due to flicker effect, ionization or "cool end" effect. If it can be eliminated, "quieter" valves should result.

Attention is devoted mainly to the smooth descent of A from unity to about 0·15, as it is believed that this represents the basic fluctuation due to "smoothed" random emission from the cathode. Such fluctuations will be governed by the ratio of impressed to initial electron velocities, that is by a factor of the form $Ve/(kT)$, where V defines the potential distribution in the valve. There is no physical potential which uniquely defines the potential distribution from cathode to anode, since this depends on the anode potential and on the depth of the potential minimum. It is found, however, that if V is taken as the potential difference between the potential minimum and the anode, A is a unique function of $Ve/(kT)$ within the limits of experimental error. This is demonstrated in Fig. 2, which

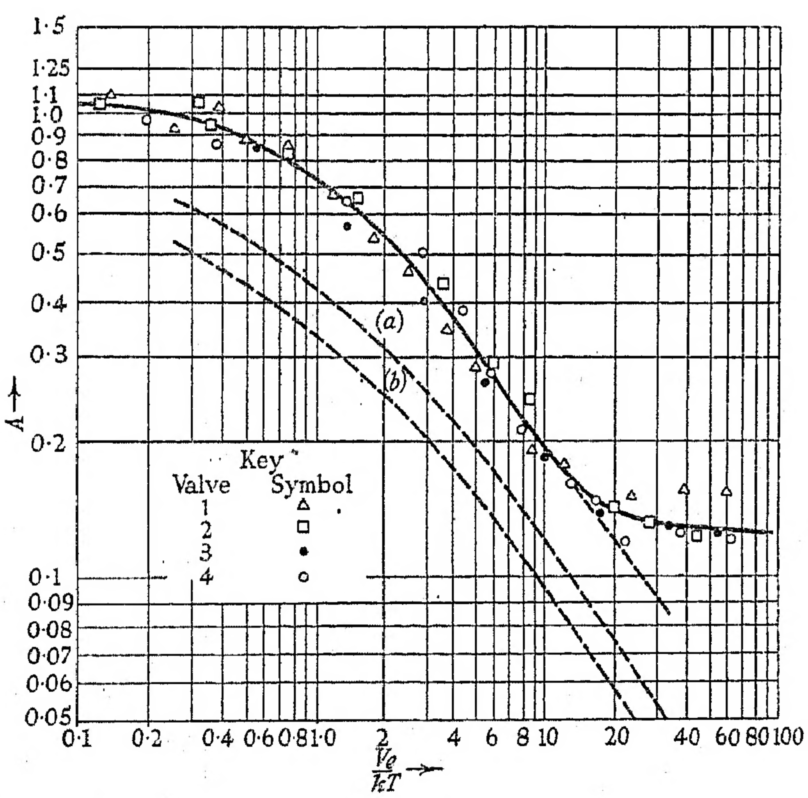

Fig. 2.—A as a function of $Ve/(kT)$, T constant. [$e/(kT)$ = 12·3 volts^{-1} when T = 940° K.]

Curve (*a*) is Schottky's prediction from shot effect, and curve (*b*) is his prediction from the thermal hypothesis.

shows the curves of Fig. 1 replotted in this form. Other measurements relating to reduced cathode temperatures confirm this result.

Schottky has predicted two values for A as a function of $Ve/(kT)$ which are believed to relate strictly to planar diodes only. The first, curve (*a*) of Fig. 2, is based on calculations of the space charge smoothing of random cathode emission and it underestimates the observed value of A by a factor of 1·6. The second is derived from the thermal hypothesis of valve fluctuations by which the fluctuations are equated to those generated by Brownian motion of electrons in a metallic resistance equal to the valve slope resistance at a temperature one half of that of the cathode. This prediction is shown by curve (*b*) of Fig. 2 and is low by a factor of about 2.

The thermal hypothesis has also been tested directly by measuring the slope resistance of the valve and determining what value of temperature T' would be required in order that a metallic resistance of equal value should yield fluctuations equal to the measured valve fluctuations. These results are shown in Fig. 3, where $T'/(\frac{1}{2}T)$, T being the

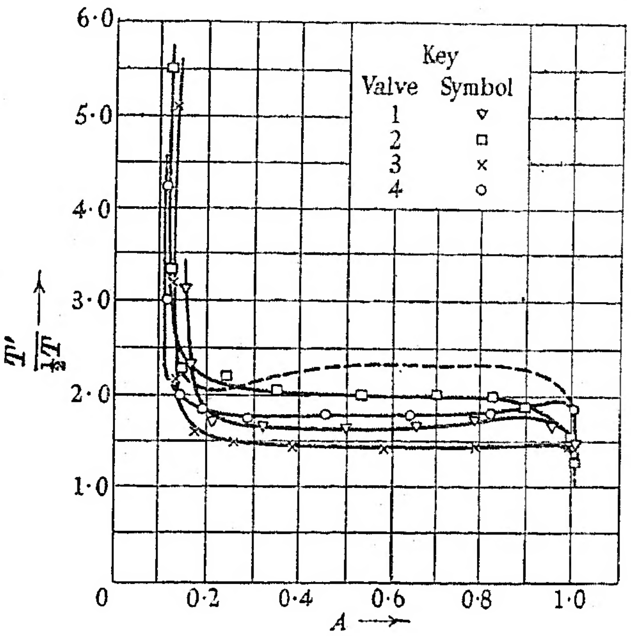

Fig. 3

cathode temperature, is plotted against A for the points on Fig. 1. For values of A between 1·0 and 0·15, $T'/(\frac{1}{2}T)$ is fairly constant at a mean value of 1·7, but rises sharply when A is less than 0·15, thus supporting the view that some spurious effect enters with the lower values of A. Ignoring the spurious effect, these curves give qualitative support to the thermal hypothesis, but suggest a quantitative error.

Moullin has suggested that A may depend on the ratio of the slope resistance ρ to the slope resistance ρ' of the cathode to potential minimum path.

He proposes either $$A = \left(\frac{\rho}{\rho'}\right)^{-2}$$

or $$A = \left(\frac{\rho}{\rho'}\right)^{-1}$$

The second of these is shown to be qualitatively correct.

The relation between these hypotheses is discussed and it is shown that if the product of slope resistance and anode current is a suitable function of $Ve/(kT)$ only, then if A is also a function of $Ve/(kT)$ only both the thermal hypothesis and Moullin's hypothesis will be qualitatively correct. It follows that qualitative agreement cannot determine which is the correct hypothesis: quantitatively Schottky's prediction based on space-charge smoothing is the most nearly in agreement with experiment.

Bell has suggested that valve fluctuations are due partly to thermal fluctuations in the valve slope resistance and partly to temperature-limited components of anode current due to "cool end" effect or other causes, and he has sug-

gested a method of assessing the magnitude of the temperature-limited component. It is shown that this method is unsound, and it is argued from the form of experimental results that temperature-limited components or current cannot be contributing appreciably to the measured fluctuations.

In an Appendix some measurements of fluctuations in magnetron diodes are described. Valve 3 was used for the tests. The results are summarized in Fig. 4. The curve with filled-in dots is reproduced from Fig. 1 and shows A as a function of I with zero axial field and variable anode voltage. The three solid curves show the effect of holding the anode voltage constant at three different values while the anode current is reduced by applying an increasing axial magnetic field. It may be seen that, at the lower values of current, A depends mainly on the current and but little on the combination of anode voltage and magnetic field producing that current.

The dotted curve was taken with much reduced heater voltage, giving a temperature-limited current of 60 μA with 5 volts on the anode. The corresponding value of A is unity. When I_a is reduced from this value by applying an increasing magnetic field, A at first falls, indicating the formation of space charge owing to the lengthened path of the electrons. After crossing the other curves, A begins to increase with increasing field and thereafter is similar to the other curves.

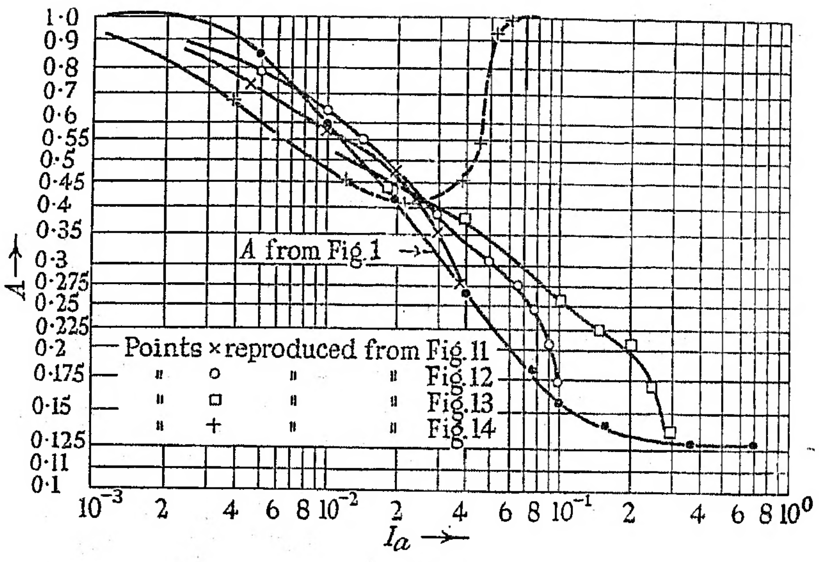

Fig. 4.—A as a function of anode current varied either by anode voltage or by axial magnetic field.

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